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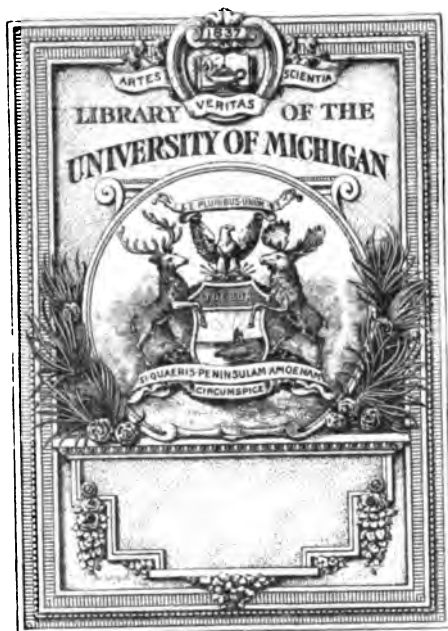
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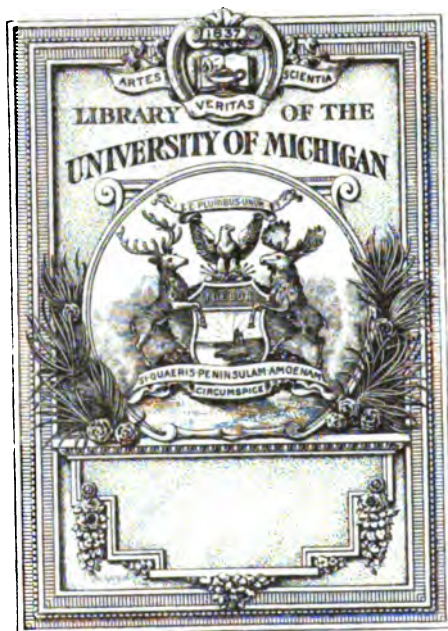
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BULLETIN No. 12.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

REPORT

ON THE

Condensation of Atmospheric Moisture.

BY

CARL BARUS.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., October 2, 1894.

SIR: I have the honor to transmit herewith a report on The Condensation of Atmospheric Moisture, by Carl Barus.

I recommend that it be published as a bulletin of this Bureau.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

Hon. CHAS. W. DABNEY, Jr.,
Acting Secretary of Agriculture.

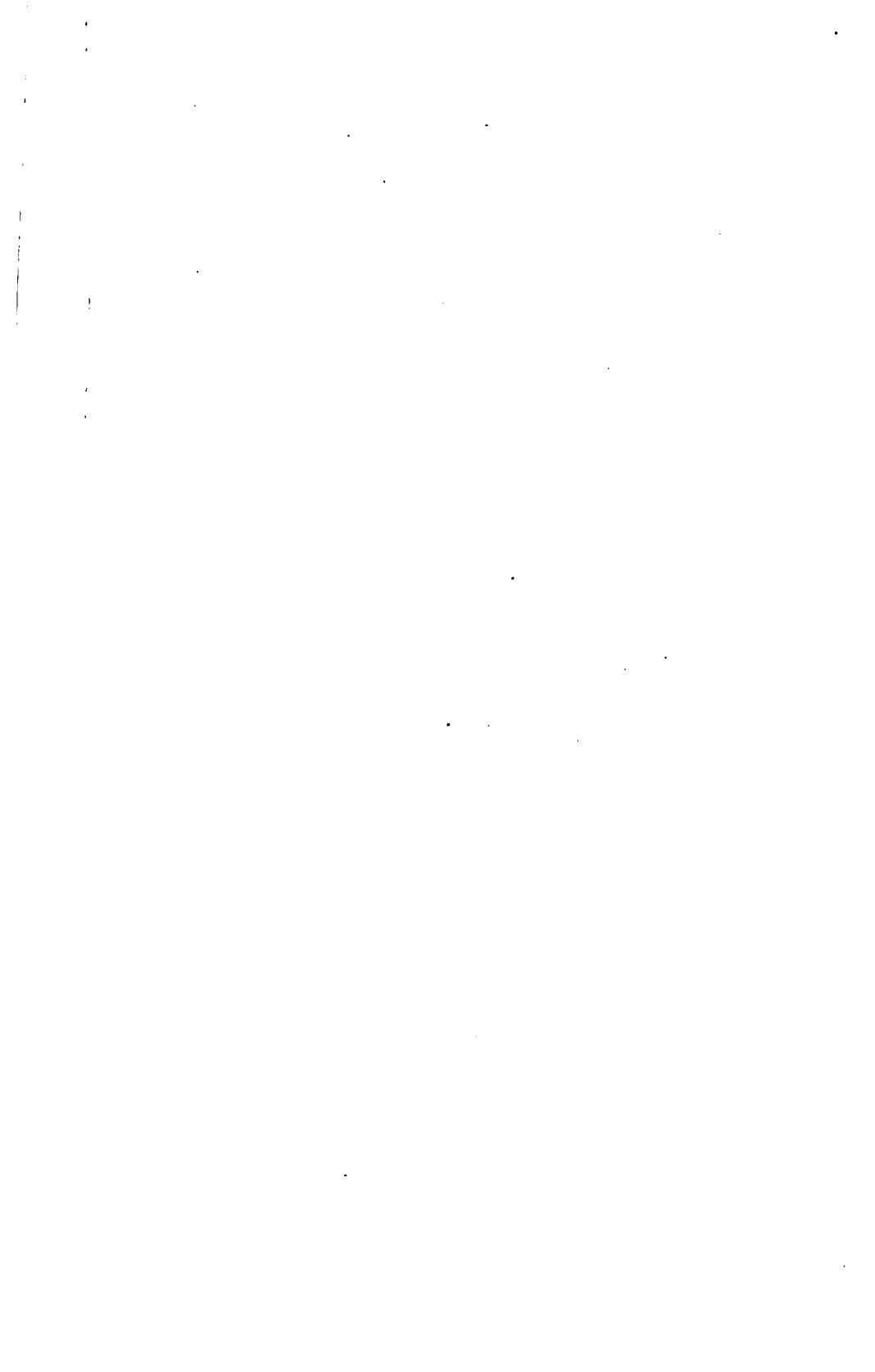


TABLE OF CONTENTS.

	Page.
Preface	9
Chapter I.—Change of physical state, in general:	
1. Introductory	11
2. Vapor condensation	12
3. Meteorological isothermals	14
4. Liquid-solid condensation	14
5. James Thomson's inflections	15
6. The two critical points	16
7. Isothermals of solution	17
8. Data for liquid solutions	18
9. Blümcke's deductions	22
Chapter II.—The colors of cloudy condensation:	
10. Purposes specified	25
11. Literature on cloudy condensation	25
12. Literature on disaggregation	27
Apparatus—	
13. The jet	28
14. Color tube. First form	29
15. Color tube. Second form	31
16. Illumination by reflection	32
17. Differential apparatus	33
Methods and results—	
18. The succession of colors	34
19. Possibility of interference	37
20. The opaque field	37
21. Color tube by reflected light	39
22. Size of corpuscles	39
23. The condensation problem	40
24. Dust and flames	42
25. Promiscuous experiments	43
26. Electric excitation	45
27. Conclusion	47
Chapter III.—Colored, cloudy condensation, as depending on air temperature and dust contents, with a view to dust counting:	
28. Introductory	51
29. The present method	52
30. Color apparatus	52
31. Influx tubes	53
32. Errors	55
33. Results. Normal atmosphere	56
34. Further data	58
35. Further data	60
36. Further data	60
37. General character of the loci	60

	Page
Chapter III.—Colored, cloudy condensation, as depending on air temperature and dust contents, with a view to dust counting—Continued.	
38. Artificially dusty atmosphere.....	62
39. Cold and warm phosphorus.....	63
40. Effect of dust contents.....	64
41. Filtered air. Small apparatus.....	65
42. Filtered air. Large apparatus.....	66
43. Apparent variations of dust contents of normal air.....	67
44. Continuation.....	69
45. Bore of the nozzle.....	69
46. Sensitiveness.....	70
47. Conclusion.....	71
Chapter IV.—The thermal topography of the free steam jet:	
Purposes of the work—	
48. Nature of the problem.....	72
49. Pressure and volume.....	72
50. Literature.....	72
Apparatus—	
51. The jet.....	73
52. Temperature measurement. Thermocouple.....	74
53. Temperature measurement. Galvanometer.....	74
Results—	
54. Notation.....	75
55. Earlier data.....	76
56. Errors.....	78
57. Further data. High temperature environment.....	79
58. Data. Low temperature environment.....	81
59. Longitudinal distribution of temperature.....	83
60. Radial distribution.....	84
61. Fall of temperature in the connecting pipe.....	86
Inferences—	
62. Structure of the jet.....	87
63. Character of the axial distribution.....	88
64. Exponential constants.....	89
65. Graphic digest.....	91
66. Effect of steam pressure.....	92
67. Conclusion.....	94
Chapter V.—Distribution of temperature in the color tube:	
68. Points of view.....	96
69. Temperature. Axial distribution.....	96
70. Digest and chart.....	97
71. Effect of pressure.....	97
72. Effect of air temperature.....	100
73. Mean coefficients.....	102
74. Summary.....	103

LIST OF ILLUSTRATIONS.

PLATE I.

- Curves *H*, showing the increase of temperature (ordinates) for different pressures (abscissas in cm. of mercury) actuating the steam jet, at different heights (*H* in cm.) above the nozzle.
- Curves *P*, showing the limiting value ($P=0$) of the temperature (ordinates) at different heights above the nozzle (abscissas in cm.) when the actuating pressure approaches zero.

PLATE II.

- Curves *H*, showing the increase of temperature (ordinates) for the different pressures (abscissas in cm. of mercury) actuating the steam jet, at different heights (*H* in cm.) above the nozzle.
- Curves *P*, showing the values of temperature (ordinate) at different heights above the nozzle (abscissas in cm.) when the actuating steam pressure has a fixed value.
- Curve *c a r*, showing the radial distribution of temperature (ordinates) in terms of the radius (*r* in cm.) of a right section, when the visible width of the section is $2r = 4$ cm.
- Curve $\pi \pi$, showing the difference of temperature (ordinates magnified ten times) between the steam box and the inside of the nozzle when pressure (abscissas in cm. of mercury) varies.

PLATE III.

- Distribution of temperature (curves *P*) on passing from the nozzle indefinitely outward, along the axis of an idealized steam jet. The ordinates are degrees centigrade and the abscissas heights (cm.) above the plane of the nozzle, supposed to lie at the origin of coordinates. Points with dashes show certain effects of increments of pressure.
- Curves *a b*, showing probable values of the pressure coefficients dt/dp , at different heights.

PLATE IV.

- Charts showing the axial temperatures in the color tube, viz:
- Curve *a c b*, axial distribution of temperature (ordinate) in terms of height (abscissas in cm.) above the nozzle.
- Curve *a c d*, same distribution for free jet.
- Curves ΘH , change of temperature (ordinate) at a given point, *H*, in terms of the actuating steam pressure (abscissas in cm. mercury).
- Curves $P H$, change of temperature (ordinate) at a given point, *H*, in terms of the temperature of the inflowing air (abscissas in degrees centigrade).
- Fig. 1. Diagram of isotherms.
- Fig. 2. Fusion isotherms of naphthalene, showing volume (c c. ordinates), varying with pressure (atmospheres, abscissas), for each of the isothermal temperatures 63° , 83° , 90° , 100° , 130° .
- Fig. 3. Isothermal behavior of a turbid solution of naphthalene in toluol.

- Fig. 4. Isothermal behavior of a clear solution of naphthalene in toluol.
- Fig. 5. Isotherms of mixtures, showing volume v as depending on pressure p , and composition ratio x . Diagram.
- Fig. 6. Steam box. Scale, $\frac{1}{2}$.
- Fig. 7. Steam jet. Full size.
- Fig. 8. Color tube with attached Bunsen jet and appurtenances. Longitudinal section. First method. Scale, $\frac{1}{2}$.
- Fig. 9. Color tube with attached jet. Longitudinal section. Second method. Scale, $\frac{1}{2}$.
- Fig. 10. Color tube arranged for reflection. Scale, $\frac{1}{2}$.
- Fig. 11. Differential color tubes. Front view. Scale, $\frac{1}{2}$.
- Fig. 12. Diagram showing the colors of Newton's interferences, by normally transmitted white light, as dependent on the thickness of the plate in ten-thousandths of a millimeter.
- Fig. 13. Differential color tubes arranged in series.
- Fig. 14. Color tube with attached heater, duster, and other appurtenances. Filters. Sectional elevation. Diagram.
- Figs. 15, 16, 17, 18, 19, 20, 21. Charts showing the margin of the opaque field in terms of the actuating steam pressure and the air temperature.
- Fig. 22. Variation of the opaque margin due to a change of dust contents. Diagram.
- Fig. 23. Diurnal variations of dust contents (empirically rated) of normal atmospheric air.
- Fig. 24. Free steam jet with attachments for measuring the distribution of temperature.
- Fig. 25. Chart showing (curves H) the increase of temperature (ordinates) for different pressures (abscissas in cm. of mercury) actuating the steam jet at different heights (H in cm.) above the nozzle; also (curve P) showing the limiting values ($P=0$) of the temperature (ordinates) at different heights above the nozzle (abscissas in cm.) when the actuating steam pressure approaches zero.
- Fig. 26. Radial distribution of temperature in a steam jet actuated by the pressure P the ordinates being degrees centigrade, and the abscissas lengths in centimeters measured along a prolonged horizontal diameter at a height H above the nozzle.
- Fig. 27. Curves showing the temperatures (ordinates) in the axis of the color tube 20 cm. above the nozzle for different temperatures (abscissas) of the inflowing air. The upper curves are obtained by a thermocouple, the lower curves by a thermometer.

PREFACE.

Following the instructions of Prof. Mark W. Harrington, it will be my purpose in the course of the present researches to trace the isothermals of water, experimentally, throughout the region of changes of physical state from liquid to vapor. By mapping out the whole of the stable contours I hope to reach definite results relative to the unstable part of their path, believing that this—the *field of collapse*, as it may be called—is of marked meteorological importance.¹ Incidentally I shall also obtain data for the law of growth of water globules, from the smallest physically appreciable dimensions to the largest attainable size, and thus supply another series of meteorological results. The subject of research considered from these two points of view may be termed the condensation problem, assuming that the stated condensation takes place in a medium of air.

Necessarily my work at the outset will consist of an investigation of promising methods, and the present bulletin contains about as much experimental evidence as I am able to adduce by the aid of the supersaturated moist air obtained from steam jets, when the results are interpreted by methods of optical interference. I make a survey of the subject in Chapter I, for changes of state in general. Chapter II follows with an account of the condensation phenomena produced by the jet method, together with their bearing in the condensation problem. Chapter III contains an application of this method to the meteorology of dust (so called). Chapters IV and V, finally, give succinct information as to the distribution of temperature met with in the jet experiments, to be used in the interpretation of Chapter II.

I had hoped to add to this bulletin certain data on the growth of water globules, to be reached by the method sketched in Chapter II, but the urgency of a change in the location of the laboratory has compelled me to break off my work at an earlier stage of progress.

My thanks are due to Prof. S. P. Langley, Maj. J. W. Powell, and Mr. Clarence King for working facilities kindly placed at my disposal, and to the Chief of the Weather Bureau, and Profs. Cleveland Abbe and Frank H. Bigelow for various points of advice.

CARL BARUS.

PHYSICAL LABORATORY,
U. S. WEATHER BUREAU, May 1, 1893.

¹ Cf. Professor Harrington's paper in the *Am. Meteo. Jour.*, IX, p. 469, 1893.

Postscript, January 28, 1895.—The present bulletin reaches my hands, now, as the mere fragment of an extensive piece of research, actively planned out over two years ago. I wish therefore to express my regret that an investigation which opened with so much promise had to be discontinued, and that during the year of my connection with the Weather Bureau a great part of my time was unavoidably taken up in first reorganizing the laboratory for meteorological research, and thereafter removing the whole of it to new quarters—an undertaking involving much labor, none of which appears in the bulletin. I wish also to express my indebtedness to the generosity of Prof. Alexander Graham Bell, without whose effective aid the reorganization would have been impossible.—C. B.

CONDENSATION OF ATMOSPHERIC MOISTURE.

CHAPTER I.

CHANGE OF PHYSICAL STATE IN GENERAL.

1. *Introductory.*—In defining my duties as a member of the Weather Bureau, Prof. Mark W. Harrington indicated that problems connected with the condensation of water from moist air were first to be considered. I was left at liberty to look at these phenomena from a general point of view, and accordingly I have commenced the study of condensation either from fusion or from vaporization, as well as from solution (liquid or gaseous). The recent theories of solution originating in the epoch making researches of Van't Hoff adduce many reasons for grouping all these phenomena under a common head.¹

To obtain a clear notion of the principle which seems to underlie all condensations, no matter what be the nature of the change of state involved, it is expedient to go back to James Thomson's² interpretation of Andrews's classical measurements. Given a fixed mass of nonsaturated vapor always maintained at constant temperature in a suitable vessel of any kind. It exerts a reacting pressure on the walls of the vessel, due to molecular bombardment, and therefore depending on the volume into which the vapor has been coerced. Let the volume be decreased, temperature being kept constant, the pressure of the vapor will increase approximately, in accordance with Mariotte's law, until eventually the vapor begins to condense. From this point on the reacting pressure remains constant throughout relatively large decrements of volume until the vapor is wholly liquid. If volume be even further decreased, pressure then again increases, but at an enormously more rapid rate than before, until the liquid-solid succession of condensations is approached and passed. The phenomenon does not terminate here, for the continued decrease of volume at constant temperature implies a remote series of condensations probably chemical in their nature—and so on indefinitely. Neither does the phenomenon begin with the vapor-liquid phase. The case of gaseous dissociation need only be considered in the inverse order to be a condensation phenomenon, which, in its turn, follows a series of analogous cases.³

¹ Cf. Blümcke: *Zeits. f. phys. chem.* VI, p. 153, 1890; VIII, p. 554, 1891; IX, p. 722, 1892.

² James Thomson: *Phil. Mag.* (4), XLIII, p. 227, 1872.

³ Cf. Barus: *Am. Jour. Sci.*, XLII, p. 147, 1891; also *Am. Chem. Jour.*, XIV, p. 191, 1892.

2. Vapor condensation.—To fix the ideas, however, it is well to restrict all remarks to vapor-liquid condensation, the successive steps of which have just been described. They are three in number and involve three apparently wholly disconnected laws. So complex a state of affairs is remarkable, and, from the rarity of true discontinuity in physical phenomena, one would be inclined to take exception to the completeness of the experiments by which these laws are deduced, even if no other evidence were forthcoming. Direct evidence, however, is available in abundance, seeing that a whole class of occurrences, such as supersaturation, retarded ebullition, etc., are ignored by the laws. The question thus accentuates the need of a method by which the volume changes of liquids may be coordinated with the volume changes of vapors by a law which shall suffer no break of continuity during the intermediate stage. This is what James Thomson did by postulating his well-known doubly inflected isothermals.

If, as is frequently advantageous, names are to be given to the two species of isothermals described, the discontinuous set may be called *empiric*, since they are most usually observed. The other, or the continuous set of Thomson, may be called *normal* or *theoretic*, for they were arrived at by induction.

Thus there are two limiting cases in relation to which isothermal condensation may be conceived to take place. In the first of these condensation is always kept at a maximum by foreign interference—for instance, by the capillary forces at the surfaces of contact between vapor and solid. If, throughout all the volume changes, sufficient time be allowed, the empiric isothermals, though broken in the manner specified, are none the less definite in character and position. The other limiting case is that in which pure vapor, perfectly free from foreign influences (i. e., out of all contact with solids and liquids), is brought to condense as a whole by some ideal means. The isothermals of this normal case are the doubly inflected lines without break of continuity, also specified. They also must be perfectly definite.

In the annexed diagram (fig. 1), let v be the axis of volumes, and let p be the axis of the reacting pressures. Temperature being always kept constant, let $abcdef$ be the (normal) isothermal, for condensation out of all contact of the vapor with solids or with liquids, and let $abgefg$ be the isothermal for a virtually perfect contact of the vapor with plane surfaces of a solid or a liquid. For this case p_2 is the ordinary vapor tension.

The important question now arises, Are there no other isothermals corresponding to the given temperature except the two extreme examples mentioned? The answer to this question brings us face to face with the thermodynamic interpretation of certain capillary phenomena. It is needless, however, to enter the subject here, further than to state that vapor tension increases with the curvature of the liquid surface, other things remaining the same. Now, as condensation (supposing

pressure or volume of suitable magnitude) must necessarily begin at some physical point or points within the volume of free vapor, the largest points will obviously be first selected; but in pure vapor none of the possible points can exceed the vapor molecule in size. Consequently at the point *c* of the diagram the reacting pressure p_3 of pure vapor can not exceed the vapor tension at a convex surface of molecular dimensions.

Something similar applies to the point *d*, or to the minimum pressure p_1 , at which the liquid is stable at the given temperature. But the physical interpretation of the state of things here is not at hand. Suffice it to say that, for thermodynamic reasons (since *b, c, g, d, e, g, b*

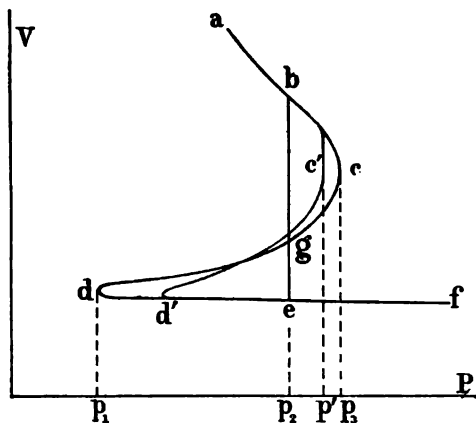


FIG. 1.—Diagram of isotherms.

is a reversible isothermal cycle), the area *b, c, g, b* must be equal to the area *g, d, e, g*. In accordance with this condition *d* is located. (Cf. Preface.)

Suppose, however, that an indefinite number of uniformly small solid nuclei be disseminated throughout the vapor, which is otherwise quite out of contact with either solids or liquids. Let the size of the nuclei be such that the vapor tension at their convex (spherical) surfaces, if liquid, and at the given temperature, would have some value p^1 between p_2 and p_3 . Then the point *c* (since it could not be reached) would be replaced by same point *c'*, and the new isothermal may be represented by same line *b c' d' e f*. In other words, between the extreme cases, *a b c d e f* and *a b g e f* an infinite number of isotherms may be conceived to exist at the same temperature, each of which corresponds to a definite size of the solid nuclei uniformly distributed throughout the volume of vapor. Under the term solid, as applied to the nuclei, nothing more is to be inferred than that they persist. Nor need any reference here be made to electrical or other methods for precipitating condensation.

3. Meteorological isothermals.—Aside from the presence of air, it is obvious that an isothermal of the form *a, b, g, c, f* can not apply to the free

atmosphere, seeing that condensation takes place there out of contact with massive solids. Neither can the normal isothermal $a c d e f$ be applicable in the meteorological case, for the atmosphere invariably carries a burden of excessively fine "dust" as one of its essential constituents. Hence lines such as $a b c' d' e f$ (or their equivalent isopiestic) must meet the atmospheric conditions, and the points c and c' will tend to coincide in proportion as the dust is of a finer quality.

Now, it is a matter of special meteorological significance that, whereas along the path $a b c$ the vapor is stable and along $d e f$ the liquid is stable, the path $c d$ is essentially unstable. For along $c d$ the reacting pressure decreases when the volume decreases, and hence this path is one of pronounced *collapse*. It is to be noted, too, that the double inflection, which is here exhibited only for the isothermals, will be a characteristic feature in any thermodynamic surface and will therefore, in general, affect the isopiestic or the adiabatics or any other order of lines drawn upon such a surface. Nor can the presence of air do more than modify the phenomenon in such a way as not to wipe out the tendency of the vapor to collapse as a whole when the proper pressure and temperature conditions are satisfied.

4. *Liquid-solid condensation*.—It is obviously very difficult to map out a concrete case of the true isothermals for the change of state from gas to liquid, and I am not aware that this has been done except in an inferential way. One may, for instance, use the intrinsic equations due to Clausius or to Van der Waals and compute the unstable contours; but this, for the time being, is an extrapolation throughout the whole meteorologic issue. For the change of state from liquid to solid, however, such representation is feasible, as it appears that the surface forces at the walls of the vessels here dwindle to smaller significance, though I am far from asserting that they are negligible. A totally distinct order of difficulties is now introduced, owing to the fact that enormous pressures are needed to bring out the details of condensation; and it is for this reason probably that the stated surface forces are of less consequence.

The only concrete example of the condensation from liquid to solid which has thus far been adduced is contained in my work on the isothermals of naphthalene. I shall reproduce its main features, with certain modifications of method here, because of its significant bearing on the general problem under consideration. The chart, fig. 2, which is one of the several series of data obtained, is laid out on a plan similar to the preceding figure, 1, the axis of volume (cubic centimeters) being vertical and the axis of pressure (atmospheres) horizontal. Naphthalene melts at about 80°C ., so that the isothermals (the constant temperature of each of which is added at the two ends of the curve) above 80° begin with liquid naphthalene, those below 80° with solid naphthalene. Five distinct isothermals (63° , 83° , 90° , 100° , 130°) are shown, and the observational points on each of them marked. It is a difficult matter in work of this kind to quite eliminate the thermal dis-

crepancy, for a liquid on freezing gives out heat, and on melting it absorbs heat. The free heat (positive or negative) thus available may be productive of distorting volume changes of no insignificant amount, and hence it is necessary to wait long enough until the heat error is dissipated. For this reason the time (in minutes) at which each observation is made is also stated on the curves by numerals referring to the points. The method of work was cyclic—i. e., starting with the liquid at a given fixed temperature, pressure was increased in successive relatively

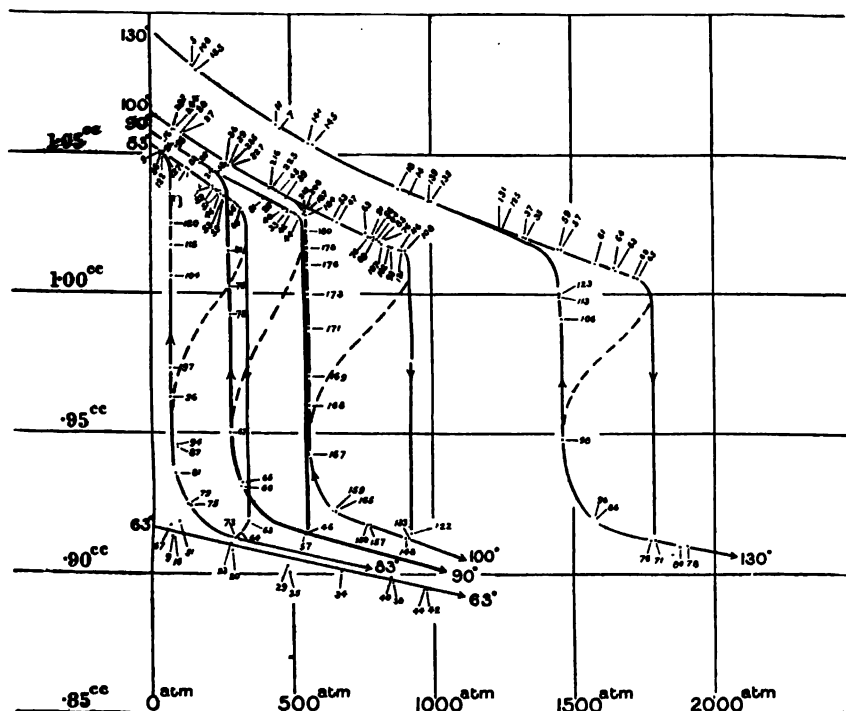


FIG. 2.—Fusion isotherms of naphthalene.

small steps until solidification ensued, and thereafter pressure was usually increased somewhat further to insure complete freezing. After this, pressure was in like manner reduced in successive small steps, care being taken to pass very slowly through the period of melting, until eventually the initial pressure (practically zero) was again reached. Arrows are added to the cyclic parts of the curves, showing their drift, and the individual observations (whether belonging to the pressure-increasing or pressure-decreasing part of the march) can be further identified by consulting the times at which they were severally made.

5. James Thomson's inflections.—The chief information to be obtained from these curves, so far as the present purposes go, lies in the difference of pressures under which, at a given temperature, freezing and melting respectively take place. Thus it takes a decidedly greater pressure to coerce liquid naphthalene at 100° from the liquid to the

solid state, than the pressure at which solid naphthalene at the same temperature freely melts. The same fact is corroborated by all the other isothermals, and is a law inherent in the phenomenon. Here therefore is direct evidence of the occurrence of James Thomson's doubly inflected cycles. I have indicated their probable contours throughout by the dotted lines contained within each cycle. The only question to be answered is the reason why the dotted lines (theoretic isothermals, from which the empiric isothermals can only be obtained inferentially, as in section 9) were not actually observed instead of the cycles. The sufficient explanation of this is the method of work, for the volume changes which are measured at the end of each step in pressure do not react on this pressure. These volume changes are merely such as actually occur when the pressure of the medium is sustained and momentarily invariable. In other words, the pressure measured is *not* the reacting pressure of this sample of naphthalene, and it is this (reacting) pressure only to which the doubly inflected curves apply. On the other hand, however, the initial or stable contours of these curves (*a, b, c* and *d, e, f*, in fig. 1) should be visible in the chart (fig. 2), and they actually are. Thus in the isothermal for 83° , at 60 and 63 minutes, curvature is distinctly (more so in the numerical data) indicated on the verge of the passage from liquid to solid, although as a rule this path is precipitous. Curvature is, however, always pronounced, and clearly so, in the change from solid to liquid, such as occurs, for instance, after 73 to 97 minutes on the same isothermal (83°), or on any of the others. The magnitude of this cyclic change, or hysteresis, is particularly remarkable. At 100° , for instance, the difference between the freezing and melting pressures amounts to over 350 atmospheres; and this for the case of a body which, like liquid naphthalene, does not easily admit of being cooled below its melting point without solidifying. Whether the pressure difference would be increased if solidification took place in a free liquid—i. e., in one which is not in contact with solids, and quite without nuclei—has not been evidenced.

6. *The two critical points.*—Another equally marked analogy between the gas-liquid and liquid-solid condensations is the occurrence of a critical point in each case. The former has long since been pointed out and is now known for a great number of volatile bodies, including steam. The occurrence of a critical point in liquid-solid condensations may be reasonably inferred from the chart, fig. 2, seeing that the vertical height of the cycles continually decreases when higher pressures and temperatures are approached. Eventually, therefore, one must reach a thermal state for which the liquid changes isothermally into the solid without marked or sudden change of volume, and beyond which the isothermals will probably be even without inflections. Other deductions may be made from the figure, but, as they have no meteorologic bearing, I will omit them.

7. *Isothermals of solution.*—In view of the detailed analogy which holds between many characters of fusion and of solution, much that

can be investigated for the simpler of these phenomena (fusion apparently) will be applicable to the other. A substance may be transferred from the solid to the liquid state either (1) by heating it or (2) by dissolving it. In general, excess of temperature or of solvent favor the diminution of viscosity here in question. A liquid on the verge of solidification or a concentrated solution is solidified or deposits solid on cooling or on the withdrawal of the solvent. In both cases the nice adjustment of molecular equilibrium is accompanied by volume hysteresis, under cooling in one case and supersaturation in the other. Hence I concluded that if under proper thermal conditions pressure alone can solidify a liquid, it can also, under proper solutional conditions, induce crystallization or the deposit of solid from solution.

Inasmuch as the preceding paragraphs show that the isothermals expressing the nature of the condensation of a gas have a complete counterpart in the isothermals expressing the solidification of a liquid, it follows that similar parallelisms will probably be manifest in the behavior of liquid and of gaseous solutions. Now, it is the latter case which forms one of the chief concerns of meteorology, since water condenses out of air and evaporates into air, so that air and moisture make up a solutional system. Having, therefore, the apparatus with which the above fusions were studied still at hand, it did not seem ill-advised to begin the meteorological work by investigating the conditions under which a solid is precipitated from solution. Presumably, as before, the cyclic changes would be more sharply demonstrable for this case than for gaseous solutions.

Having used the term molecular or chemical equilibrium, I must indicate its direct relation to the mechanism of a vapor tension. Whenever one part of a complex body passes from a first to a second molecular state as fast as the other part of the body passes from the second to the first state, then there is molecular equilibrium at the interface. Thus in a closed vessel water ceases to evaporate when as many molecules are rejected by the liquid as it receives from the gas.

In carrying out the work for the isothermals of solution, two serious difficulties presented themselves. The first is due to gravitational separation. Whenever the dissolved solid is solidified at a given temperature by pressure, the precipitate tends to fall to the bottom of the tube. After relieving the pressure the original solution can not be reproduced, for the solid contained in the bottom of the tube can only reach the top by the excessively slow process of diffusion. As the result of a large number of compressions, therefore, the lower layers are soon more than concentrated and contain excess of solid, while the upper layers are relatively dilute. The measurements, therefore, become exceedingly difficult of interpretation, for there is no guaranty that the solution treated is ever homogeneous. The only way of overcoming this irregularity which occurs to me would consist in dissolving the solid

in a gelatinous menstruum, in which case, however, the menstruum itself must be separately investigated. The second difficulty encountered is the small amount of volume change which accompanies precipitation. It is only a fractional part of the liquid solution (and not the whole, as in case of fusion) which undergoes change of state. The preliminary problem therefore is the selection of bodies which not only show the largest contraction, but which at the same time are remarkably soluble; but very soluble solids as a rule show hysteresis or cycles of such an enormous extent that the available pressures are powerless to solidify them in the absence of crystalline nuclei. In short, my work on the isothermals of solutions, although carried through an interval of 2,000 atmospheres, has not led to clear-cut data, and I will therefore reject the whole of it excepting only a few illustrative results obtainable by compressing threads of liquid contained in capillary tubes.

8. Data for liquid solutions.—The following table contains results for the apparent compressibility of naphthalene dissolved in toluol. A thread of the solution was compressed between terminal threads of mercury, under conditions of constant temperature, θ ; and the compressibility (β) is estimated in terms of the change of length of the thread of solution. The table contains the time (in minutes) at which the individual readings for pressure and for volume decrement ($\frac{v}{V}$) were taken. Two cases are given. In the first of these a few crystalline nuclei were always present in the (turbid) thread; in the other the solution was clear and without nuclei.

TABLE 1.—*Isothermal behavior of a solution of naphthalene, concentrated at 29°, in toluol. Initial length of thread 9.85 cm at 30°.*

[Treatment in capillary tubes.]

Turbid solution: $\theta = 30.1^\circ$ ($29.7^\circ - 30.6^\circ$).				Clear solution: $\theta = 31.0^\circ$ ($31.8^\circ - 31.5^\circ$).			
Time.	Pressure.	$10^4 \times \frac{v}{V}$	$\beta \times 10^6$.	Time.	Pressure.	$10^4 \times \frac{v}{V}$	$\beta \times 10^6$.
45.....	30	0		20.....	43	0	
46.....	112	91	111	25.....	119	61	80
50.....	110	91	114	32.....	117	71	96
52.....	177	173	120	34.....	242	183	92
55.....	173	163	115	40.....	234	183	96
57 ¹	273	305	125	42.....	348	284	93
60 ¹	264	325	140	48.....	340	284	96
75 ¹	261	376	165	50.....	471	386	90
80 ¹	259	386		60.....	459	386	93
85 ¹	183	264		62.....	462	315	
92 ¹	191	264		65.....	463	315	
95 ¹	99	142		69.....	225	203	
104 ¹	104	142		85.....	230	213	
109.....	22	61		97.....	61	51	
120.....	25	61		101.....	62	51	
123.....	170	244	125	105.....	480	407	85
135.....	157	213	120	112.....	459	396	87
139.....	201	274	129	120.....	456	406	80
150.....	198	274	125				
160 ¹	255	366	130				
167 ¹	252	366	135				
	252	366	135				
175 ¹	296	508	165				
	160	295					
180 ¹	0	61					

Tube breaks at 650 atmospheres. No freezing.

¹ Freezing.

² Solution.

³ Flocules.

The results of this table are given in the chart, figs. 3 and 4. Straight lines connect the individual observations and arrows show the directions in which pressure varies. Points belonging to different cycles are distinguished by little circles. The volume decrements (ordinates) corresponding to each pressure (abscissas) are represented positively. Numerals show the times at which the observations were taken.

Considering the turbid solution first, the compressibility is regular between 45 and 57 minutes. Between this and 80 minutes partial

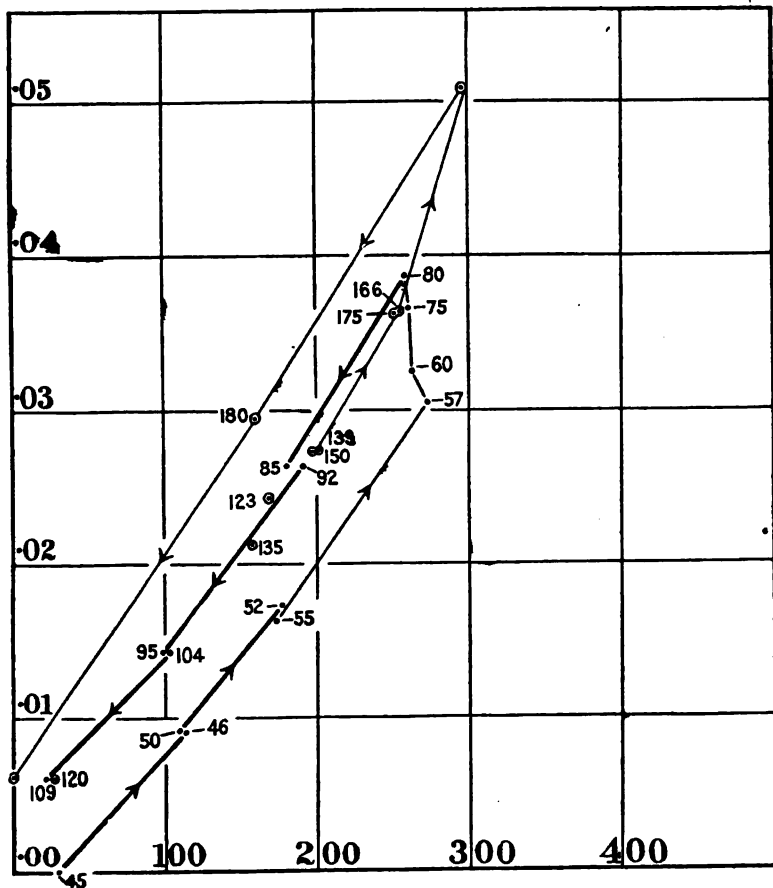


FIG. 3.—Isothermal behavior of a turbid solution of naphthalene in toluol.

solidification has set in with a shifting of the fiducial zero, both because some of the dissolved solid is thrown out permanently and because the mercury thread has been parted in the endeavor to actuate the solidified thread. When pressure is reduced, the compressibility is again regular. Finally the second cycle resembles the first in most respects. Throughout the work the mean apparent compressibility exceeds $\beta = 0.000110$. It is usually much larger, particularly when the solidification occurs.

Fig. 4 for the clear solution shows a shifting of the fiducial zero, due to separations of the mercury thread. Otherwise the results are fairly regular. In one important particular these results differ from fig. 3, namely, that the mean apparent compressibilities for the clear column are always smaller than $\beta=0.000\ 096$. Indeed, for the turbid column the compressibility actually increases from about 0.000 120 to 0.000 150 as more of the solid has been thrown out; whereas in case of the clear column the average apparent compressibility¹ is about 0.000 090.

The reasons for this difference of behavior are not for to seek, but they are of great importance in relation to the present inquiry. In a

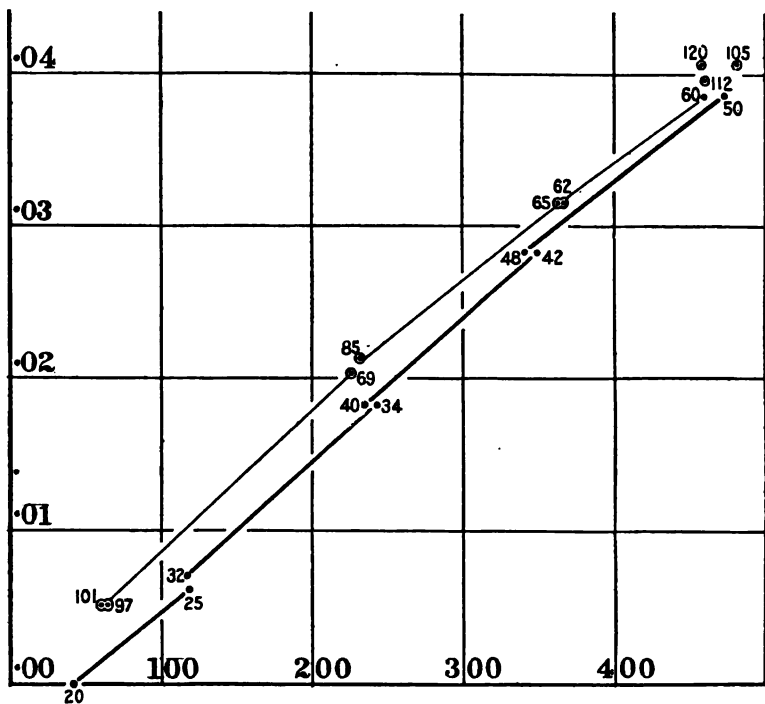


FIG. 4.—Isothermal behavior of a clear solution of naphthalene in toluol.

solution turbid with excess of solid there is a fixed state of chemical equilibrium corresponding to each pressure. When pressure increases isothermally more solid is thrown out, and when pressure is diminished the solid is, so far as possible, redissolved. The "turbid" isothermals are therefore necessarily empiric. This change of state is therefore equivalent to an increased rate of volume decrement, and hence the observed apparent compressibility is abnormally large as compared with the same solution free from crystalline nuclei. "Clear" isothermals are thus essentially normal or theoretic. The results here given are therefore identical in kind with the data found and interpreted for silicate

¹ Since the data for compressibility were merely to be compared, there was no need of correcting for the volume expansions of the glass tube.

solutions.¹ In the latter instance I was able to increase the solid in solution regularly and obtained an equally regular increase of compressibility to correspond with the amount of available solid. So marked were the results that the final compressibility was fully three times the initial compressibility at the same temperature, whereas the usual effect of clear solution is a marked decrease of compressibility.

The second important result contained in Table 1 is the absence of solidification in case of the clear column, even when pressures very much larger than those applied to the turbid column were brought to bear at nearly the same temperature. Here, therefore, is indisputable evidence in favor of a solutional cycle, or of solutional hysteresis, of the same kind though much larger in magnitude than was found for fusion.

In the following table I add corroborative results for a solution of zinc sulphate, concentrated at about 40° and then cooled down to 10°. *R* denotes the resistance of a filament of the solution varying in length with the volume decrement due to compression. From this and the volume of the reservoir the total isothermal volume was computed for each pressure.

TABLE 2.—*Isothermal behavior at 10° of an aqueous solution of zinc sulphate, concentrated at 40°.*

Time.	Pressure.	<i>R</i> .	Volume.
0	100	12, 200	0.7329
15	298	12, 500	.7314
23	550	12, 700	.7299
34	899	12, 800	.7289
47	1, 255	13, 000	.7371
57	1, 798	13, 400	.7244
60-75	2, 038	(a)	-----

^aBroken. On removing from piezometer, the solution is clear, showing absence of solidification. Compressibility too small for measurement.

Thus the striking fact is brought out that the solution, already cooled 30° below its saturation temperature, is capable of withstanding at least 2,000 atmospheres without solidifying. The experiment could have been made even more striking by cooling the solution down to a lower temperature. Another result of the table is the low apparent compressibility obtained for the solution, as compared with pure water. Had there been flocules of salt present the compressibility would have been larger than for that of water for reasons already stated.

To summarize therefore, the chief feature of the results relative to the isothermals of solutions is the occurrence of a pronounced volume lag, in virtue of which solution at a given temperature takes place at a lower pressure than the corresponding precipitation. When precipitation eventually does occur it is partial, and in this respect the present behavior differs from the corresponding case of freezing from fusion.

¹Barus: Am. Jour., xli, p. 110-116, 1891.

In other words, the solution phenomena contains a clear-cut example of chemical equilibrium varying with temperature and with pressure, the meteorological bearing of which will already be manifest in the course of the following paragraphs.

9. *Blümcke's deductions.*—Questions relating to the thermodynamics of mixtures or solutions have been treated with great generality by Van der Waals¹ and others. Blümcke's² geometrical constructions, however, afford a clearer view of the matter, when the isothermals of mixed substances are to be considered. I will therefore reproduce a typical case of his results here. Given two coercible gases, which in their liquid state are perfectly miscible, let the thermal state of each lie below its critical temperature.

In the annexed diagram, fig. 5, let P , V , X be the axes of pressure, volume, and composition, respectively. If the mass be always a unit, then for $X=0$, the mixture will consist of one of the substances and for $X=1$ of the other of the substances, exclusively. Hence in the diagram, $ngoprs$ may represent the theoretical, $ngzrs$ the empiric, isotherms of the first body, and $abcdf$ the theoretical, $abuef$ the empiric, isotherm of the second body; so that g and b are the points of incipient, e and r the points of completed, liquifaction of the two bodies, at the same temperature. But equally definite points of incipient and completed condensation exist for each of the infinite number of mixtures of the two bodies; or, in other words, there is a curve, gib , in space at which nuclear condensation begins, and a corresponding curve, rme , at which it is complete. These two curves belong simultaneously to the theoretic and to the empiric isothermal surfaces.

The empiric surface ($rzgibuem$) is a conoid so circumstanced that any sectional plane parallel to XV (and therefore a plane of constant pressure) cuts the conoid in a straight line. In other words, the conoid is generated by a straight line moving so as to be always parallel to the plane XV , while the ends of the line travel on the space curves rme and gib respectively.

To find the isothermals corresponding to a given composition, x , a plane must be passed parallel to PV , at the stated distance x from it, and the lines of intersection with the surface will represent both the theoretic and empiric isotherms for the mixture. The figure contains a section of this kind about midway between the end planes ($x=0$ and $x=1$). The two isothermals are shown at $hitvjk$ and at $hivmk$. Now, it is clear at once that the empiric isotherm ivm will, in general, intersect a number of the generatrices of the conoid. Hence ivm must be a curved line, such that pressure continually increases while volume diminishes, if the path irm is to be stable, as it actually is. Finally the thermodynamic relation of the two isotherms $itvjm$ and ivm implies that equal areas itv and vjm are thus intercepted.

¹ Van der Waals: Ostwald Zts., v, p. 133, 1890.

² Blümcke: loc. cit.

When temperature increases, the form of the thermodynamic surface will also change. Thus if one of the ingredients of the mixture be at or above the critical temperature, the corresponding part of the isothermal surface will be more and more without double inflection, and the isothermal sections will be correspondingly modified throughout the surface. This is the case for water vapor suspended in the atmosphere, to which detailed consideration will be given in the course of development of the present investigation. Here it is merely neces-

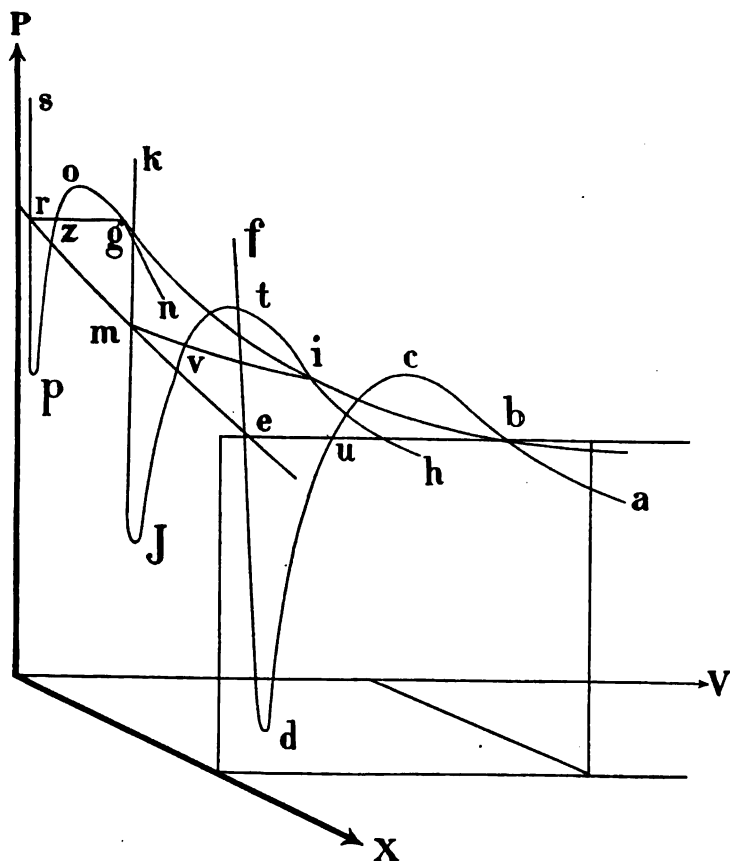


FIG. 5.—Isotherms of mixtures.

sary to point out the application of the surface, fig. 5, to the case of the solid-liquid solutions contained in tables 1 and 2.

Both ingredients of the solution (naphthaline and toluol, for instance) lie below their respective liquid-solid critical temperatures. Hence the isothermals for $x=0$ and $x=1$ will have the general form instanced in fig. 5. So long, moreover, as the remarks are restricted to the precipitation of one only of the ingredients out of the solution, the character of fig. 5 need not be modified. Hence $h i t v j m k$ may be taken as the theoretic or normal isothermal along which compression is directed

for the case of the clear solution, and *h i v m k* as the path of compression for the turbid solution. In short, therefore, compressibility, regarded as the rate at which volume changes with pressure, will be in a marked degree greater along the path *i t* than along the path *i v*, and this is precisely the dictum of the results contained both in tables 1 and 2.

CHAPTER II.

THE COLORS OF CLOUDY CONDENSATION.

10. *Purposes specified.*—Turning now to the subject proper of the present research—the passage from water vapor to liquid in a menstruum of air—it follows, from what has been stated, that as one can not work with free air, the method applicable to the condensation problem must be so chosen as to trace the progress of the experiment at each moment throughout the course of the change of physical state. Only by producing instantaneous condensation can the conditions of a free atmosphere be simulated experimentally, and a phenomenon, independent of the surface forces at the walls of the vessel, be observed. Above all things it is therefore necessary to obtain some means of discriminating between vapor and a collection of indefinitely small water globules. Thus, for instance, the difference of specific inductive capacity for the two cases might furnish an available criterion; but this method would present great experimental difficulties. Nor is it clear whether any inkling could thus be obtained relative to the size of the water globules. Both these desiderata are supplied within certain limits by the colors of cloudy condensation, and it is to the description of a method of producing them at will, of interpreting color in terms of size of particle, and of making the phenomenon tributary to the problem in question, that the present chapter will be devoted. If these elusive color effects can be brought thoroughly under control, then an experimental method of much greater scope than the earlier observers have appreciated must necessarily result.

Incidentally I will add other allied experiments—such, for instance, as relate to electrification, etc.

11. *Literature on cloudy condensation.*—For information on the present status of the subject, I am here as elsewhere greatly indebted to Prof. Cleveland Abbe, who, with his usual courtesy, placed his detailed knowledge wholly at my disposal.

The fundamental researches of Coulier¹ and Mascart,² and of Aitken,³ though closely allied with the present work, refer chiefly

¹ Coulier: *Jour. de Pharm. et de Chim.* (4), xxii, p. 165, 1875; Cf. *Fortschritte der Physik*, xxxi, pp. 471, 870.

² Mascart (see Coulier) verified Coulier's work.

³ Aitken: *Nature*, xxiii, pp. 195, 384, 1880; *Trans. Roy. Soc. Edin.*, xxx, p. 337, 1881.

to the function of dust. They are, moreover, too well known to need comment here.

With regard to the color phenomena, the first definite observations were made by Forbes,¹ who worked with immense high-pressure steam jets. For this reason, probably, he saw only the yellow-browns of the first order.

The systematic research of the subject followed at a much later date, and is due to Kiessling². His treatment is exceptionally thorough and virtually contains all that is known of the color phenomena by exhaustion. I shall have occasion to refer to these experiments again, and here merely state that neither the original tubular form nor the later spherical form of Kiessling's apparatus is suitable for my purposes. The condensations produced by suddenly expanding dusty air (partial exhaustion) and the colors thus evoked, however startling, are necessarily fleeting and can not be brought under control.

The subject is next taken up by R. v. Helmholtz,³ chiefly with the object of developing a new method for measuring the depression of vapor tension produced by solution. The function of dust is considered incidentally at some length, and a size is assigned to the cloudy particles. Color phenomena are not specially observed until in a second paper R. v. Helmholtz⁴ corroborates Kiessling's researches by the aid of steam jets, and particularly with reference to the condensation induced by electric discharges. He analyzes the opaque steam jet into zones of color, obtaining a serviceable scale. After a series of striking experiments, v. Helmholtz concludes that a disturbance of the chemical equilibrium of the surrounding medium produces a condensation effect on the jet similar to the dust effect. Omitting further reference to this important research for the present, I shall proceed with the corroborative paper of Bidwell's.⁵ He suggests that the occurrence of an opaque jet is due to electrical influences similar to those by which Lord Rayleigh⁶ produced a coalescence of scattering water jets. Hence Bidwell believes the particles of an opaque steam jet to be larger than the corresponding particles in ordinary jets.

In the recent paper on the subject, Mr. J. Aitken⁷ argues very soundly that Bidwell's view can not be correct, and thus substantially corro-

¹ Forbes: *Phil. Mag.* (3), xiv, pp. 121, 419, 1839; *ibid.* (3), xvi, p. 102, 1840.

² Kiessling: *Naturw. Verein, Hamburg-Altona*, viii (1), 1884; *Göttinger Nachr.*, v, p. 122, 1884; "*Dämmerungserscheinungen*, Chapter v, pp. 133-145, Hamburg, L. Voss, 1888.

³ R. v. Helmholtz: *Wied. Ann.*, xxvii, p. 508, 1886.

⁴ R. v. Helmholtz: *Wied. Ann.*, xxxii, p. 1, 1887.

⁵ Bidwell: *Electrician*, xxiv., p. 146, 1889; *Phil. Mag.* (5), xxix, p. 158, 1890.

⁶ Rayleigh: *Proc. Roy. Soc. Lond.*, xxviii, p. 406, 1879. According to G. Wiedemann (*Beiblätter*), xiv, p. 291, 1890, and Wiedemann's *Electricität*, i, p. 27, these phenomena were observed by Father Gordon, of Erfurt, about one hundred and forty years ago. They were frequently repeated by Fuchs in 1856 and studied by Beetz in 1871.

⁷ Aitken: *Proc. Roy. Soc.*, LI., March, 1892, p. 408.

borates R. v. Helmholtz,¹ who had proved the occurrence of smaller particles in the opaque jet as compared with the ordinary jet some five years before. After classifying the various methods² by which the appearance of a steam jet may be made to pass from the ordinary to the abnormal aspect, Mr. Aitken discusses the causes underlying each experiment in detail. An important novelty, namely, the effect of the temperature of the medium surrounding the jet, is here introduced. To explain all the phenomena, a repulsive force acting between the particles below a certain temperature is postulated in addition to the repulsive action of the electrically charged particles. In the second part of his paper Mr. Aitken takes up the colors of cloudy condensation and gains an advantage by passing the steam jet through tubes illuminated by transmitted light. Unfortunately he does not perfect this arrangement, but proceeds to produce these phenomena by the exhaustion method, virtually repeating Kiessling's work; but the breadth and thoroughness of Mr. Aitken's work, together with the fact that it was done quite independently of the German researches, enhances the value of its bearing on the present subject.

This hasty survey will suffice for the present, as more specific information is to be brought forward in the course of the following paragraphs. I have omitted references to atmospheric phenomena, such, for instance, as are discussed by Kiessling *loc. cit.*, and Abbe,³ because they do not fall within the limits of the present paper.

[Among recent contributions I may refer to a discussion between Mr. Aitken, Mr. Bidwell, and myself in *Nature*, XLIX, pp. 340, 363, 388, 1894, as to causes which induce aqueous condensation; and particularly to a paper by E. Kaiser in *Wied. Ann.*, LIII, p. 667, 1894, who shows that the coalescence of liquids due to electrification is the result of purely mechanical pressure. This new result effectually clinches the argument made in section 26 of this Bulletin.—January 30, 1895.]

12. *Literature on disaggregation.*—Incidentally I will have to refer to the scattering of particles from the surface of a very hot metal, as well as to the analogous phenomenon produced by an impinging beam of ultra violet light, by electrification, etc. The work which has been done

R. v. Helmholtz: *Wied. Ann.*, XXXII., p. 2, 1887. After referring to Kiessling's results, V. Helmholtz remarks: "Da letztere (Diffractionsfarben) von der Grösse und Regelmässigkeit der Nebeltröpfchen abhängen, so liegt der Schluss nahe, dass durch die electrischen Kräfte die Condensation * * * beschleunigt wird. Die Art, wie sich die Farben mit der Elektrisirung der Spitze ändern, scheint dies zu bestätigen. Ist nämlich die Menge der ausströmenden Elektrizität sehr gross, so wird der Strahl bläulich bis tief Azurblau, wie der Himmel. Diese Färbung deutet auf sehr zahlreiche, sehr kleine, und sehr regelmässige Nebeltröpfchen hin. Lässt der Strom der Elektrizität allmählich nach, so wird das Blau immer weisslicher, was auf das Hinzutreten grösserer Tropfen deutet," etc.

²These are: (1) Electrification of jet, (2) an increase in the number of dust nuclei, (3) cold or low temperature of the air, (4) high pressure of steam, (5) obstructions and rough nozzles. Aitken, *loc. cit.*, p. 409, et seq.

³Abbe: *Am. Meteo. Jour.*, v, p. 529, 1889.

on these subjects is, however, very extensive, so that only a mere mention¹ of prominent papers can be made here.

APPARATUS.

13. The jet.—To answer the requirements of section 10, the endeavor must be made to construct an apparatus by which any of the colors of cloudy condensation may be produced at pleasure, and be maintained at the greatest brilliancy possible for any length of time. In the color

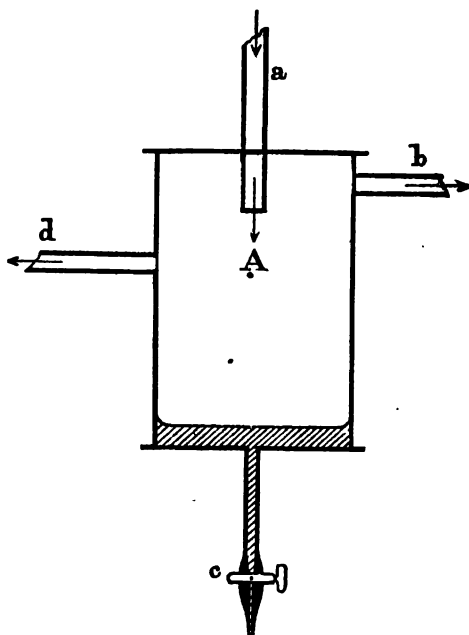


Fig. 6.—Steam box. Scale $\frac{1}{2}$.

estimations, furthermore, it is desirable, if not necessary, to have a given normal or fiducial case of condensation constantly at hand, for comparison with the results obtained in any variation of experiment. Section 17. Only in the case of vapors issuing from a jet are the preliminary conditions filled, for here the particles are supplied as fast as they are removed out of the field of view, and they may be removed before they change in size appreciably. Section 23. The jet, moreover, may either be fed with pure steam or with compressed air supersaturated with aqueous vapor. Section 25.

When steam is used alone, it must be available in large quantity, at a pressure of about 1 atmosphere or more. This pressure may then be reduced by an ordinary steam cock. To dry the steam, it is conveniently passed into a cylindrical box, A, fig. 6, through the vertical pipe *a*, surmounted by the cock specified. It is conveyed to the jet by a lateral pipe, *b*. The water which collects is discharged from time to time through *c*, at the bottom of the box, and a pipe, *d*, communicates with an open mercury manometer for the measurement of pressure. It is

¹ The reader is referred to Nahrwold: Wied. Ann., xxxi, p. 467, 1887; xxxv, p. 107, 1888. Berliner: Wied. Ann., xxxiii, p. 289, 1888. Wiedemann and Ebert: Wied. Ann., xxxiii, p. 241, 1888. Elster and Geitel: Wied. Ann., xix, p. 588, 1883; xxvi, p. 1, 1885; xxxi, p. 109, 1887. Guthrie: Phil. Mag. (4), xlv, p. 257, 1873. Koch: Wied. Ann., xxxiii, p. 454, 1888. Kayser: Wied. Ann., xxxiv, p. 760, 1888. Hertz: Wied. Ann., xxxi, p. 983, 1887. Stoletow: C. R., cvi, p. 1149, 1888. Hallwachs: Wied. Ann., xxxiii, p. 301, 1888. Lenard and Wolf: Wied. Ann., xxxvi, p. 443, 1889. Righi: Mem. Acad., Bologna (4), ix, p. 369, 1888. Crookes: Nature, xlv, pp. 212, 455, 1891. Prof. A. W. Wright, of Yale College, investigated this subject extensively at a much earlier date.

often necessary to have two afflux pipes, *b*, one of which is provided with a suitable stopcock. Section 17. *A* may be made of stout tin plate, thoroughly soldered.

A jet of almost any kind, with a smooth hole about 1 mm. in diameter, is satisfactory. It may be conveniently shaped from lead pipe. When the variations of the color phenomena are to be quantitatively studied, it is advisable to make the jet¹ as shown in fig. 7. Here *a b* is a brass tube about 10 cm. long and 1 cm. in diameter, the end *b* of which is threaded both on the outside and inside, so that a small thin-walled nipple, *c*, closed at the outer end, may be inserted. Into the top of *c*, a hole, *d*, is smoothly drilled. The outer thread at *b* is useful in screwing the jet to the color tube (sections 14, 16) into the center of which *c* projects. The open end *a* of the jet is to be connected with the tube *b* of the steam box, fig. 6, by a short piece of stout rubber tubing.

If this jet is so made, the diameter of the hole *d* is accurately known, and hence the quantity of steam discharged into the color tube can be computed by Napier's or Grashof's formulæ for any pressure in *A* (fig. 6). Furthermore, the amount of adiabatic cooling of the steam issuing

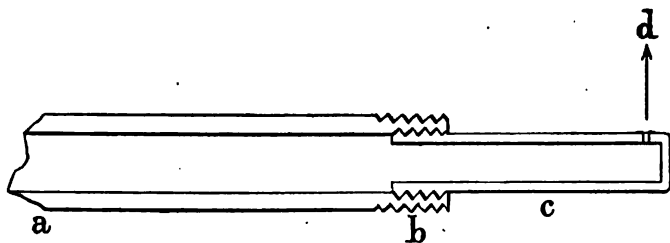


FIG. 7.—Steam jet. Full size.

at *d* is also easily calculated. Both of these quantities are of importance when the color phenomena are to be systematically studied.

Finally, by varying the number of holes in *d*, an increased intensity of some of the very faint colors, or a peculiar persistence of others, is often obtained. Section 25.

The jet is virtually a region at which steam passes suddenly from a high temperature to a relatively low temperature. A mass of steam is thus continually maintained in a definitely supersaturated condition. This state of things is accentuated by the cold air with which the jet comes in contact.

14. The color tube. First form.—In making the observations the chief desideratum is a closed receptacle with a clear field of view from which all extraneous light is, so far as possible, excluded. If a tube closed with glass plates is used, these at once cloud over when exposed to steam, and the tube is then worthless for observation, except for the londest of the colors. To look directly into steam is equally unsatis-

¹ See next chapter, section 45, et seq.

factory, besides being a severe tax on the eyes. One way of overcoming the difficulty is to heat the plates with a Bunsen burner above 100°C . If the glass is poorly annealed a smooth piece of wire gauze may be stretched tightly over it to obviate breakage. All this is inconvenient. A special steam jacket at the plates is inefficient, while tubes open at one end would not meet the requirements of the quantitative work. Hence I proceeded as follows:

The color tube is shown in its various forms in figs. 8, 9, 10, 11. In all these cases the tube proper, *C*, *A*, *A*, *B*, is the same; but it is placed

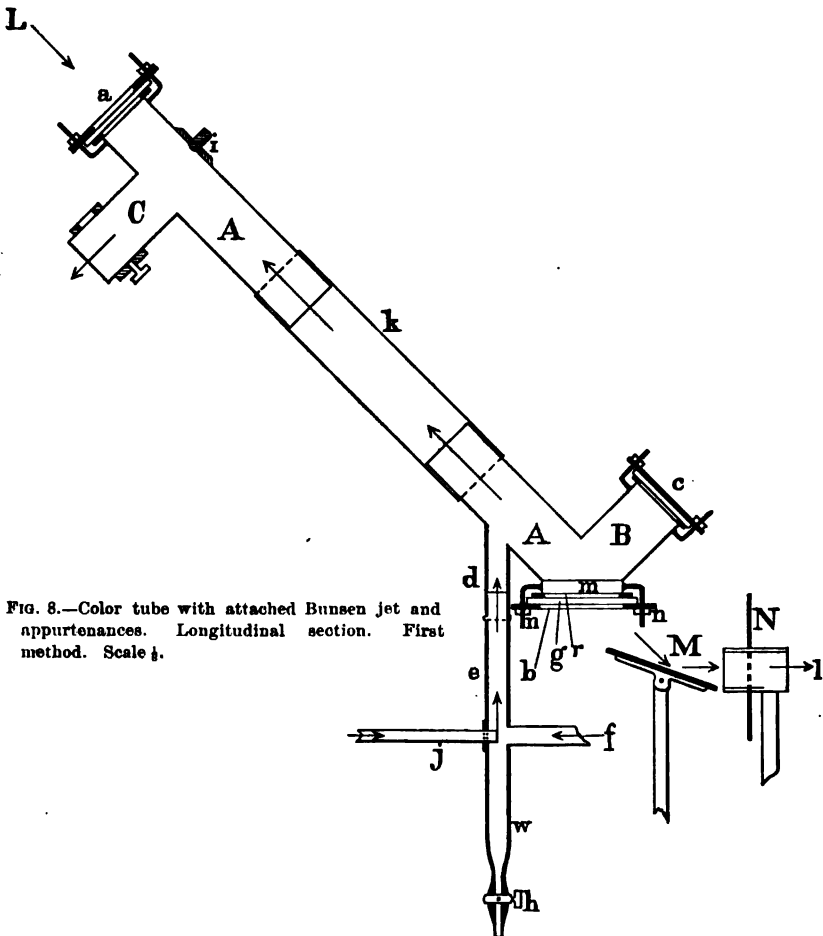


FIG. 8.—Color tube with attached Bunsen jet and appurtenances. Longitudinal section. First method. Scale $\frac{1}{4}$.

in different positions to obtain different effects. This tube is preferably of thin sheet zinc or copper, to prevent rusting, and the part *A* *A* is about 60 cm. long and 5 to 7 cm. in diameter. A lateral branch *B*, of the same diameter and about 10 cm. long, enters the main tube at right angles, at the lower end, fig. 8, and the common bottom *m*, of the two tubes is closed by a plate of clear glass *g*, held in place by the ring *b*

and the nuts *n*. This joint is made quite tight by a gasket of rubber *r*, forced against the common rim of the tubes by the nuts just mentioned.

In the same way the top *a* of *A A* and the outer end *c* of *B* may be closed, as the figure clearly shows the efflux pipe *C* does not need an attachment.

The mixture of steam and air (obtained in a way presently to be shown) enters near the bottom of *A A*, through another lateral tube *d*, whose axis is in the plane *A B* and nearly vertical when the plate *g* is horizontal. The vapor, after passing through *A A*, is discharged by a large tube, *C*, near the top.

In the position of fig. 8, sky light *L* enters the tube at *a*, and, after passing through the steam and the window *g*, is conveniently observed by aid of a little mirror *M* and a screen *N*, with a circular hole in front of *M*. This device shuts off all light except the rays *l* from *a*. *B* is closed by an opaque plate. When the steam passes through *A A*, the window *a* soon clouds over but this is no great disadvantage, for *a* is a mere source of diffuse white light. The window *g*, however, must be quite transparent, otherwise the colors of the steam could not be seen. To secure this end, I poured a little water into the trough *m* at the bottom of the tube. A beautifully clear field is thus obtained, the observer looking, as it were, through a plane parallel plate of water. Additional water which collects here from the steam is eventually discharged through *d*.

The feeder in this case resembles a Bunsen burner supplied with steam instead of gas. The jet proper (shown at *j*) has the form given in fig. 7, and is screwed into the brass tube *e*, the top of which fits snugly into *d* of the color tube. Any water which collects here falls into the prolongation *w* and may be discharged through the stopcock *h*. When the jet is in action, air enters through lateral tubulures *f*, only one of which is shown in the figure.

This apparatus is frequently convenient, because the jet *j* can be so easily supplied with pure air or with air impregnated with dust or vapor in any manner. It shows a fair succession of blues and (under special treatment) intense yellows and orange browns of the first order. The field becomes quite opaque with the merest trace of dust, etc. But, as a rule, the colors are not brilliant, nor can the purples and blues of the second order be seen with certainty. I was for a long time at a loss to ascertain the cause of this, and, after spending much time on useless modifications, I finally found that the amount of air which the jet *j* can drag through the tube *E*, 2 cm. in diameter, is usually insufficient to make the colors glow. Finally, for a high pressure influx, the water in *m* is apt to become turbulent.

15. The color tube. Second form.—Hence I made a radical modification by discarding the old form of jet and inverting the whole arrangement in the manner shown in fig. 9. Steam now enters the tube *A A*

directly by the jet *j* screwed into it near the bottom. Air is supplied through *C*, which is of the same diameter as *A A*. Moreover, *B* is now the efflux, the plate having been removed. Sky light *L*, transmitted through the tube by means of the adjustable mirror *M* and the window *a*, is observed through the inclined plate *g*. Here a difficulty presents itself, inasmuch as *g* at once clouds over; but I eventually overcame

this by moistening the inside of *g* with a solution of caustic potash, applied through *B* with a sponge probang. In this way a clear field is again obtained for some time at least, after which the moistening must be renewed. The inclined position of *g* makes the whole window easily accessible, and a special hole, closed by a cork, may be cut in the elbow for inserting the probang when *B* is otherwise engaged. The tube *d* is also closed with a cork. The observer faces the plate *g* symmetrically and looks down into the color tube *A A*, while a screen, *S*, cuts off all extraneous light.

With this apparatus a brilliant field of color is obtained so that minute differences may be detected, and I thus investigated the scale given below (section 18) between the intense oranges of the first order and the final greens of the second order, after which the colors are too faint for recognition. In the latter case, since low pressure steam must be employed, an advantage is secured by drilling three or five holes in the jet *j*.

Fig. 9 shows that the tubes *A A* slide into a snugly fitting envelope *k*. The system may, therefore, be shortened for observing very intense colors, or lengthened for faint colors. Section 25. Either end of *A A* may also be rotated, which in many experiments is necessary. Section 23.

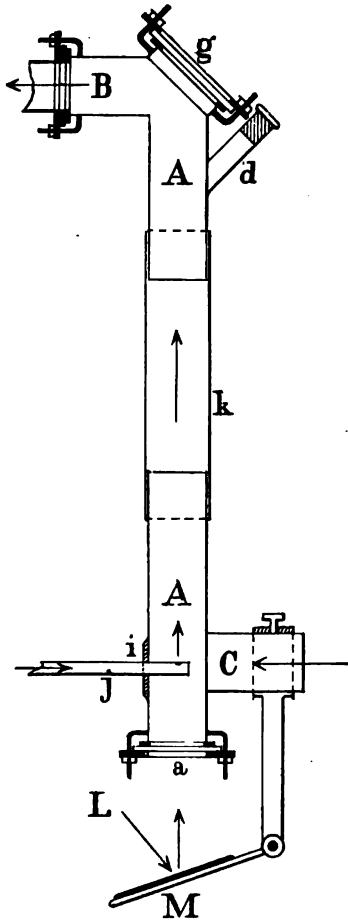


FIG. 9.—Color tube with attached jet. Longitudinal section. Second method. Scale $\frac{1}{2}$.

16. Illumination by reflection.—In order to ascertain the source of color in these experiments, it is desirable to test the cloudy condensation by reflected light as well as by transmitted light. This may be done by placing the color tube, as shown in fig. 10, where the steam from the Bunsen jet enters at *d* and passes out at *C*, as in fig. 8. The plate *a* is now made opaque and the plate *c* clear, while the plate *g* is replaced by a mirror, reflecting upward, and which has a little of the

amalgam scraped away from the lower surface. Hence an observer, regarding the tube from below, may look in the direction of the axis *A A* upward. The mirror *M* and screen *N* of fig. 8 may also be used. Fig. 10 shows that sky light *L* now enters through *c* and is reflected by *g* parallel to the axis of the tube, a condition which may be tested by temporarily opening *a*. If the inside of the tube is painted dark, no light can reach the eye except in so far as it is reflected (*l*) from the cloudy particles introduced into *A A* through *d*.

A plate of water, *m*, above *g*, is necessary here, as in fig. 8, to obviate clouding.

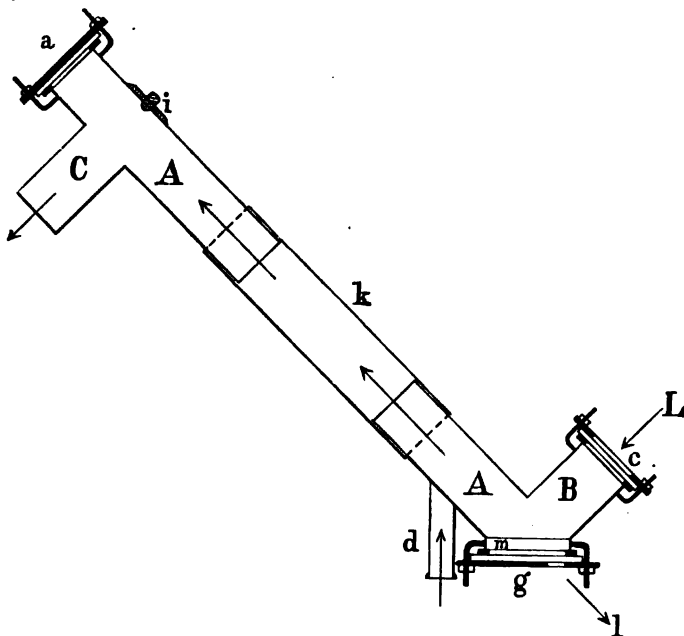


FIG. 10.—Color tube arranged for reflection. Scale $\frac{1}{4}$.

A similar result can be secured by introducing a little mirror on a stem through *C* in fig. 9 and shutting off the light at the top of the tube. An observer looking into *C* may then view the color effects along the axis of *A A*.

17. Differential apparatus.—Color tests are not as a rule satisfactory for quantitative work, unless some fiducial field of color is always at hand for comparison. For this reason the apparatus (fig. 9) was further improved, as shown in fig. 11, in front view. The parts are lettered as above. Fig. 11, therefore, consists of two color tubes, identical in every respect and admitting of an independent use of both eyes. Sky light is introduced by the mirrors *M M'*. The observer looks down into both windows *g, g'*, at once. The two tubes are connected rigidly by the double bridge *m*, and a horizontal rod or stout tube, *n*, joining the bridges, is grasped by an ordinary clamp for fixing the system in place.

If the jets are identical, and communicate through identical lengths of tube with similar tubes *b* (fig. 6) of the steam box *A*, the colors seen by both eyes must necessarily be identical. This state of affairs may be tested once for all. Supposing, therefore, that the right tube, *A' A'*, is left without interference, the other tube, *A A*, may be manipulated

in various ways. Thus one may change the temperature, or the pressure, or the composition of the influx of air or other material at *C*; or the number and size of the holes in the jet may be varied, or the steam variously impregnated with other gases before it escapes at the jet, etc.

In all such cases the tubes *A A* and *A' A'* are connected in multiple arc, as it were. But if the jet be removed from *A' A'*, and the discharge from *A A*, after passing through a suitable length of wide tube, be eventually passed through *A' A'* without further interference, then these two tubes are connected in series. This adjustment will, I believe, lead to important applications of the present apparatus.

Reviewing the experience of this section it appears that the adjustment of air and steam which secures the clearest field in a color tube must be made as nicely as the adjustment of air and gas in a Bunsen burner. Otherwise the colors are either dull or faint. Doubtless the efflux may at times be stimulated to advantage by an auxiliary ventilating tube containing its own jet, without interfering with the color tube itself. Sections 23, 25. In using the differential apparatus it is convenient to prolong one of the air tubes *C* above the head, but within easy reach, of the observer.

METHODS AND RESULTS.

18. The succession of colors.—The first question to be disposed of is the succession of colors. Here I am able to proceed with considerable certainty, seeing that there is a rich harvest of experimental material available. I will arrange these colors in Table 3, stating briefly how they were obtained, and placing the colors where I think they belong. I will also add Quincke's¹ revision of the colors of Newton's rings, when seen normally by transmitted white light, as quoted by Kohlrausch,² for comparison.

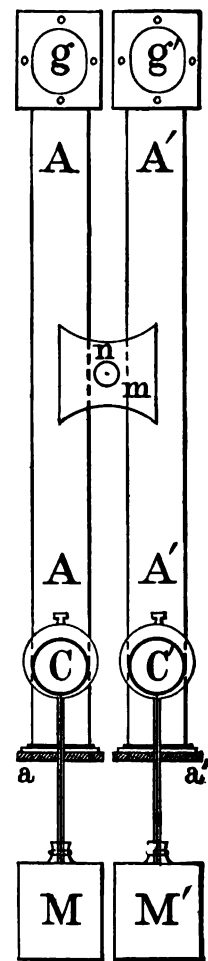


FIG. 11. — Differential color tubes. Front view. Scale $\frac{1}{4}$.

¹ Quincke: Pogg. Ann., CXXIX, p. 180, 1866.

² Kohlrausch: Leitfaden, 5 ed., p. 340.

TABLE 3.—Showing the succession of colors.

[Data of the last column for air, white light, and normal incidence.]

By exhaustion.		Experiments with jets.				Colors of Newton's interferences.	Thickness of plate of air in millimeters.
Kiesling. 1884.	Aitken. 1892.	Helmholtz. 1887.	Aitken. 1892.	Barus. 1892.	Present method.		
				White.	Fig. 8 with sulphur. § 25, moist gas jet.	White.	.000,020
			Yellow.	Yellow.		Yellow white.	.000,048
				Orange.		Brown white.	.000,079
				Brown.		Yellow brown.	.000,109
				Opaque.	§ 9, efflux violent.	Brown.	.000,117
				Opaque.		Red.	.000,129
				Opaque.		Carmine.	.000,133
				Dark violet.	§ 17, efflux intense.	Dark-red brown	.000,137
				Indigo.		Dark violet.	.000,140
				Blue.	§§ 17, 14.	Indigo.	.000,153
				Gray blue.	§§ 17, 14.	Blue.	.000,166
				Blue green.	§§ 17, 14.	Gray blue.	.000,215
				Green.	§§ 17, 14.	Blue green.	.000,252
				Green yellow.	§§ 17, 14.	Pale green.	.000,268
				Straw yellow.	§ 17, 14.	Yellow green.	.000,275
				Muddy brown.	§ 17.	Yellow green.	.000,282
				Pale purple.	§ 17.	Green yellow.	.000,287
				Pale violet purple.	§ 17.	Yellow.	.000,294
				Pale violet.	§ 17.	Orange.	.000,332
				Pale indigo.	§ 17.	Brown orange.	.000,364
				Faint green.	§ 17, jet nearly shut off.	Light carmine.	.000,374
				Faint yellow green.	Long tube, § 25.	Purple.	.000,413
				Beyond recognition.		Violet purple.	.000,421
						Violet.	.000,433
						Indigo.	.000,455
						Dark blue.	.000,474
						Green blue.	.000,499
						Green.	.000,550
						Yellow green.	.000,564
						Dull yellow.	.000,575

Jet of continually decreasing intensity of flow from the top to the bottom of this series of colors.

Kiessling¹ was the first to call attention to the striking similarity of the order of colors at the centre of his field, to certain Newtonian interferences ("gewisse Newton'sche Interferenzfarben"). After him Aitken² points out the same fact more at length. The remarks of these gentlemen, however, are cursory and vague. Thus Aitken believes the colors to be interferences by reflection of the second and third order, whereas my results show interferences by transmission of the first and second order, terminating at the third.

Kiessling's results need some explanation. His first series of colors is produced by compressing surcharged, suitably dusted, air, and then allowing it to expand suddenly to atmospheric pressure. The experiment being made in a glass sphere illuminated by sunlight, the colors are observed in the axis of illumination. The succeeding series are obtained by aid of an exhaust pump. They are less easily located relatively to Newton's scale (see end of table) than Kiessling's first series. Indeed, I am at a loss to know, from his description, whether the whole of the four series (the colors gradually become fainter till they fade completely) can be obtained in a single exhaustion, or whether they are the results of successive independent exhaustions. I have inferred that the latter case holds, and have so placed the colors. In any case one would expect them to become gradually more complex and mixed. The first series is intensely brilliant. Diffractions necessarily enter.

Aitken, who exhausts long tubes, gets a wider range of colors running (as I interpret them) from the first into the third order.

Von Helmholtz saw all his colors in the successive regions of an open steam jet, and reasonably inferred that the remote and cooler parts contain the larger particles. Aitken's jets play into tubes, as stated above. Section 11.

With regard to my own work, most of the colors from the browns of the first order to the purples of the second can be produced in the tube, fig. 8, by simply decreasing the pressure under which the steam issues from about 80 cm. of mercury to zero. But all the colors are dull, the initial browns muddy, and the final purples so faint as to be hardly perceptible. However, to obtain the white, yellow, orange brown, and brown red of the first series in a state of great brilliancy, it is sufficient to let the steam jet suck the flame of sulphur into one of the air tubes *f*, fig. 8, the others being closed. In this way particles of sulphur are volatilized, unchanged, in an atmosphere of SO₂ and they reach the jet in a state of extreme comminution. Moreover, the full heat of the flame is sufficient to prevent all condensation (white), in spite of the sulphur nuclei; but by gently withdrawing the flame the cloudy condensation gradually becomes incipient (yellow) and eventually more marked

¹ Kiessling: "Dämmerungserscheinungen," p. 140, 1884.

² Aitken: loc. cit., p. 433: "As no white follows the first blue it seems probable that the first spectrum * * * is not observed; * * * ." But this is the property of the first order of reflected interferences only, as stated in the text.

(brown). Hence these water globules must be of an extreme order of minuteness, their size increasing actually from zero (vapor) to the dimension corresponding to brown. When the flame is withdrawn the field at first becomes opaque, and then runs through the blues and subsequent colors of the schedule—a result also agreeing with the inference stated.

Similar effects, but less striking, may be obtained with a Bunsen burner.

To obtain all the colors (except the initial white and light yellow, perhaps) brilliantly, and with a special view to minute differences of tint, the apparatus figs. 9 or 11 must be used. This is the way in which the table was constructed.

In addition to the data of the table, the pressure in the steam box, which under fixed conditions gives a definite color, might have been added. But this is the purpose of the next chapter.

19. Possibility of interference.—If now the two parts of the above table be compared, there can be no doubt that the succession of the colors of cloudy condensation is identical with the corresponding succession in Newton's rings, of the first and second order,¹ seen by transmitted light under normal incidence. Section 20. Thus it is worth inquiring whether this is more than a coincidence, or whether small water globules, all of the same size, color normally transmitted white light, like thin plates.

For a given homogeneous color, if I be the intensity of the incident light and k the reflection coefficient (0.04—0.05 for the given conditions), then, after a single transmission, the interference maxima and minima are $(1-k)^2 (1+k^2) I$ and $(1-k)^2 (1-k^2) I$ —that is, they differ only very slightly and the rings are scarcely perceptible. But if there be an indefinite number of particles, all of the same size, available, then this process is indefinitely repeated in such a way that while the light already colored is not extinguished the admixed white light becomes continually more fully colored. Thus, after a sufficient number of transmissions, the emergent ray may show intense color.

Hence, wherever particles are in great abundance, full and deep colors may be looked for; and when particles are not present in great quantity the colors are necessarily pale, dependent as their intensity is on the frequency of transmission. Clearly, when the jet is nearly shut off, the mixture is more dilute than for intense jets, while in both cases the vapors fill the color tube by expansion.

20. The opaque field.—Between brown and dark violet in the colors of the first order there is an opaque region. Sometimes the brown takes on a reddish hue and sometimes the violet appears purplish. But the opaque region of indefinable color (section 25), either in long or short color tubes, remains. Indeed, it is a characteristic landmark in the color territory. Being absent in exhaustions, it is clearly to be

¹ The colors fade at the beginning of the third order.

referred to the jet, and is to be interpreted in accordance with the researches of Osborne Reynolds¹ on the flow of liquids in pipes. Reynolds found that a colored jet passing through clear water remains uniformly filamentary, so long as a certain critical velocity of efflux was not exceeded. After this the jet breaks up suddenly and violently into eddies. In the present experiments this critical velocity coincides for steam with the opaque field of the color tube; or, in other words, at this rate of efflux the stability of the jet breaks down. Here, therefore, one would scarcely expect to find particles of the same size throughout.

But this reason is not quite adequate; for, if the intensity of the jet be still further increased, magnificent browns and oranges appear. To account for opacity it is thus essential to inquire into the relation of color to size of particle, at the point where color is extinguished.

In the annexed diagram, fig. 12, I have laid off Newton's colors as abscissæ, by simply platting off equal distances for each step of color.

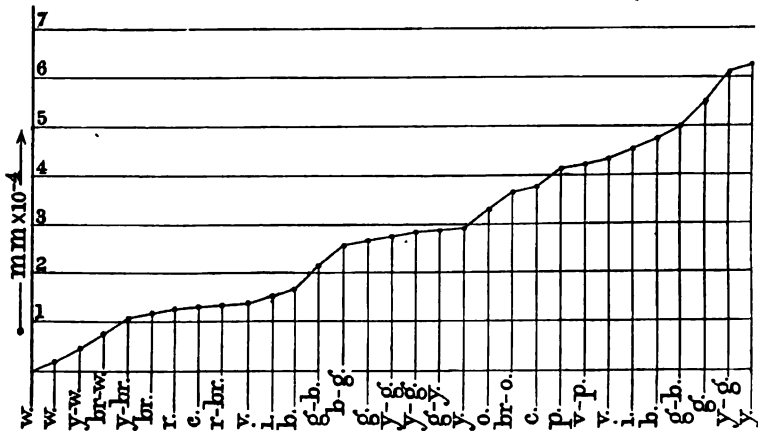


FIG. 12.—Diagram showing the colors of Newton's interferences by normally transmitted white light, as dependent on the thickness of the plate in ten-thousandths of a millimeter.

The ordinates are the corresponding diameters of the particles as given in the above table, and referred to air.² Thus it is seen at a glance that whereas, between white and brown and between violet and green, the colors change slowly and uniformly for relatively rapid increments of diameter, quite the converse of this holds good for the intermediate space between brown and violet. These hues would be very sensitive as a criterion for variations of the size of particles. Furthermore, a mixture of these colors is virtually black to the given conditions of transmitted light. Hence, if a stable but rapidly-flowing steam jet topples out of equilibrium just at this region of colors, an opaque field would seem to be inevitable.

A similar explanation may be offered to the straw color of the yellow

¹ Reynolds: Phil. Trans., London, III, p. 935, 1883; cf. p. 957.

² The water particles being smaller than this in the inverse ratios of the indices of refraction. Nothing would be gained by platting cubes of diameters.

following the blue greens; but here the insufficiency of ventilation is already a matter of consequence.

21. Color tube by reflected light.—If the jet which has been made opaque by dust or otherwise, and which in the free air appears blue (say) by transmitted light, be projected against a dark background, the complementary purple appears distinctly. Similarly in the color tube, if any part of the field be dark, this tends to take on the complementary hue of the field proper. Phenomena such as these are not simple, for they may result from physiological contrast and be merely subjective, or they may be truly physical.

Hence I made a special study by aid of the apparatus fig. 10, where the only light which can reach the eye (after proper screening) is that reflected by the steam corpuscles themselves. Looking into a tube of this kind, when no steam is admitted, the sides and opaque top *a* are faintly seen. Again, when pure steam, either without air or with filtered air, passes, the colorless clearness remains and the presence of steam reveals itself to the eye only by the shifting and dancing of the interior. When, however, dusty air is admitted, the column is at once opaque, of a pale neutral white color, and, so far as I could see, it makes no difference what the color of the transmitted light may be, or how the tube is manipulated.

Now this is precisely what one would expect, since the case is nearly the converse of section 19. For a single particle and homogeneous light, the beams which interfere are kI and $kI(1-k)^2$; i. e., they are weak but nearly equal in intensity, and the interference is very perfect and brilliant. But it is not capable of indefinite repetition, for after each interference the direction of the ray is reversed. Hence such light, if at any depth, is either entrapped in the color tube or it can only emerge from the tube (no matter whether front or rear end be considered) by being transmitted through the particles as in section 19. Light, however, which has already been colored by reflective interference and is now also compelled to interfere by repeated transmission, can only have retained the colors simultaneously present in both complementary colors. Hence it is virtually extinguished, and all one would expect to see is a dull white effect of diffuse light. In the same way light colored by repeated transmission could not survive reflective interference.

Finally, the only case in which colors by reflection are anticipative is the one presented at the beginning of this paragraph—the case where the free mantle of the jet is looked at against a dark background; for inasmuch as the interference by reflection is under like conditions much more intense than interference by transmission, the former, up to a given normal depth, might well prevail over the latter and hence be appreciable.

22. Size of corpuscles.—In so far as the views just presented are correct, the size of the prevailing particles is at once given in terms of the

colors of the column seen by transmitted light. It is merely necessary to divide the data of Table 3, in section 18, by the refractive index of water (practically to multiply those numbers by three fourths) to obtain the diameters of the particles producing a given color. Thus it appears that if the prevailing diameter be (say) 0.000,004 cm., the first of the visible colors, the yellow of the first order, looms into view. If (at the present stage of completion of my apparatus, section 17) the prevailing diameter be 0.000,040 cm., the last of the visible colors, the faint green at the end of the second order, will appear. Between these extremes something over fifteen different steps of diameter are recognizable.

It is interesting to compare this order of values with the data obtained by v. Helmholtz (loc. cit.). Utilizing the equation due to Lord Kelvin,¹ according to which, at a fixed pressure and temperature, the excess of vapor tension at a convex spherical surface is directly proportional to the surface tension and inversely to the radius of curvature, v. Helmholtz found by direct experiment that diameters between 0.000,015 and 0.000,026 cm. must have been encountered in his work. This is very near the mean of the values found above from interference data. It corresponds to the field between blue of the first order and purple of the second order, and this is the most intense and persistent part of the field.

To recapitulate. If the colors of cloudy condensation seen under normal incidence (in tubes) be regarded as cases of Newton's interferences by transmission, the order of succession, the occurrence of intensity and of faintness of color, the position of opacity, the absence or partial absence of color by reflected light, and the mean size of the active particles is well represented. This does not yet amount to a proof of the proposition as against diffraction;² but it is certain that the increase or decrease of the size of particles has been correctly interpreted in terms of color qualitatively at least, if not quantitatively, and that the absolute sizes derived can not be far wrong. Bearing this in mind, the color scale may be safely accepted. I shall probably recur to the matter more rigorously at some other time, and whatever correction be necessary can then easily be applied.

23. The condensation problem.—With these views laid down, the remarks of earlier paragraphs (sections 10, 17) may be resumed. In the differential apparatus, fig 11, let the two tubes *A* and *A'* be connected in series, as shown in the annexed diagram, fig. 13. Here the jet of *A'* is removed, and the vapor discharged from *A* is conveyed by a sufficient length of tubing, *D*, of the same diameter, into *A'*.

Then the progress of the condensation—i. e., the difference in the size of water globules in *A* and *A'*—is at once given by the difference of color of the two tubes.

¹Sir William Thomson: Proc. Roy. Soc. Edin., 1880.

²For in both cases the superposed maxima and minima must for any homogeneous color lie at distances apart proportional to the wave length.

The time taken by the vapor in making this passage, or the velocity of the current, can be accurately determined as follows: After a permanent colored field has been established, let the flame of a Bunsen burner be quickly moved across the air hole *C*. The effect of this is to superheat the steam issuing from the jet, and therefore a momentary flash of bright light is seen in *A*, followed at once by an opaque field due to the (cold) dust in the wake of the flame. This flash travels like a clear bubble through the whole length of tubing *D*, and is eventually seen at *A'* quite as brilliantly as at *A*. It is therefore only necessary to note the time between the transit of the Bunsen flame across *C* and the flash in *A'*, in order, with the known length of tubing *D*, to determine the rate of flow.

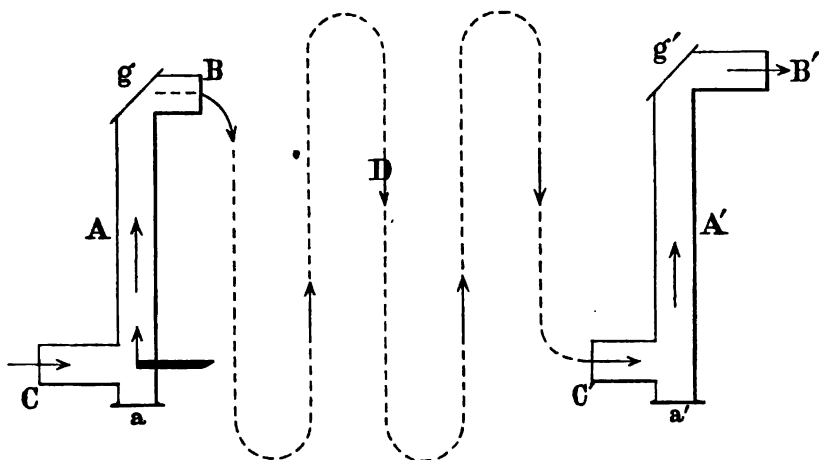


FIG. 13.—Differential color tubes. Arranged in series.

Inasmuch as this is a problem into which I am entering at some length, I will here only cite a random example:

Length of tubing *A D A'* (with allowances for ends), 300 cm

Time between flashes, 1.2 seconds.

Color of *A*. Green, yellow, blue, opaque.

Color of *A'*. Green, yellow, blue, opaque.

In other words, under these conditions there is no perceptible condensation (i. e., enlargement or decrease of the water globules) in six-fifths seconds. It follows from this result that a very considerable length of tubing, *D*, is required in these experiments. One difficulty is to be guarded against—the train *D* introduces an appreciable resistance to flow. Hence the ventilation is apt to fall below the necessary value, whereupon the colors in *A*, and particularly in *A'*, become dull. I think this can be counteracted by attaching an auxiliary vertical tube with an especial ventilating jet at *B'*. In this way the experiment proper is left without interference.

Quite a number of other questions, chiefly in reference to the flow of gases in tubes, and to jets, suggest themselves for solution here, into

which I will not enter. Temperatures at any part of the system may be measured, thermoelectrically at least, and within certain limits they may be varied. Concentrated sunlight, for instance, can be made to actually permeate the substance of the current. Again, the discharges of two independent different colored tubes *A* may be mixed in the train *D* and caused to react on each other while the effect is observed in *A'*, etc.

The other two factors which enter prominently into the present work are the amount of adiabatic cooling at the jet (which is, perhaps, open to computation and also to thermoelectric measurement, and which may be varied by connecting the color tubes in multiple arc, as shown in fig. 11, and putting a stopcock in one of the tubes, *b*, fig. 6) and the temperature of the medium into which the jet discharges. To study the latter case (supposing the color tubes connected in multiple arc, fig. 11), *C* is to be joined with a train of tubing supplying air at any temperature and suitably dusted.

Results so obtained, in addition to their meteorologic bearing, have a general physical significance as well. The reasons¹ why an intense or intensely supersaturated jet is (cæt. par.) shattered into smaller fragments than a gentler efflux will be briefly indicated in section 27. The three experimental facts on which I am justified in putting stress are: (1) the occurrence of a marked degree of supersaturation; (2) the color-producing particles are an almost instantaneous growth; (3) after being produced they retain their individuality as to size indefinitely (relatively speaking and proper conditions presupposed). These, I think, will adequately account for the sudden action and the equally sudden and definite cessation of the drop-producing tendency exhibited in the above experiments.

24. Dust and flames.—Utilizing the apparatus above, I made a great number of special experiments, into which, however, I can only enter here in a cursory way.

If, when the apparatus, fig. 8, is in action and the field of the usual gray-blue color, any dust be set free in the neighborhood of the air tube *f*, the field at once becomes opaque. What is meant by dust here is not so much the noisome article of household economy, nor smoke necessarily. Dust in the present sense is preferably far more comminuted material (section 27), such, for instance, as arises out of a clear perfect Bunsen flame, or from glowing (not smoking) charcoal (Japanese punk), or from cold phosphorus, or from the sodium tinge in the outer mantel of an alcohol burner, or from a sulphur flame (Kiessling), or from the surface of an almost tensionless liquid like ordinary concentrated sulphuric acid (v. Helmholtz), etc. Take the apparatus (fig. 8) with all the air holes open, and let a small clear Bunsen flame be placed on the table above the level of *f*. No effect is produced on the color of the

¹The ingenious and picturesque view of the case taken by Mr. Aitken will be found throughout his paper, but particularly on page 423. Cf. section 11 above.

field; but if the same burner is put on the floor in the free air, much over a meter below f and even laterally from it, the densely opaque field soon appears and persists for some time, even after the burner is again placed above the table. This conveys some notion of the sensitiveness of this apparatus, and the dusty exhalation of the little flame.

Indeed, if the air tube C of the apparatus fig. 9 be prolonged as far as the ceiling of the room, it will catch the fountain of dust issuing from a small Bunsen flame on the floor at a distance of 12 feet below the mouth of the tube. The field, all but colorless before (faint blue, second order), becomes densely opaque.

As it seems to me, the underlying cause of this striking activity is not merely the traplike action by which the flame collects atmospheric dust, but rather the additional fact that many of the great chunks of such material (metaphorically speaking) are heated to the point of disintegration and volatilization. Thus a whole cloud of nuclei comes into being where a single one existed before; and thus one might expect the hot flames like burning oxyhydrogen (Coulier) to be more active than cold flames like alcohol, since a scattering of planets into nebulae is the work to be done. R. v. Helmholtz,¹ who is among the chief students of this particular subject, calls attention to Giese's² important discovery of the diffusion of ions out of the flame proper, and their continued activity³ at some distance from it on all sides. Von Helmholtz regards it not improbable that many of these ions are neutralized in the steam jet, and there, by a kind of molecular percussion, induce cloudy condensation—an exceedingly beautiful hypothesis which he is loth to abandon, although throughout his paper his stronger judgment seems constantly to urge him in the direction of more humble references to atmospheric dust. Von Helmholtz does not make a clear case; but the question is an open one and a decision will be difficult, for the experiments, to be worth anything, must be faultless.

25. Promiscuous experiments.—If a compressed gas (oxygen) be admitted into the color tube by a collateral jet, the colored field becomes clearer. Admitted with steam into the steam box, the gas pressure replaces the steam pressure, so that without further increasing the flow of steam the colors can be made to pass from the second to the first order, through brown, orange, yellow, almost to white. Thus, by using very little steam (the jet alone showing greenish of the second order) and increasing the gas pressure, I have chased the colors through "opaque" without losing a transparent field. In this way I sometimes detected a reddish hue on passing from dark violet to brown;

¹Von Helmholtz: loc. cit., p. 7, 8.

²Giese: Wied. Ann., xvii, pp. 236, 519, 1898.

³Recalling the more recent researches of Arrhenius (Wied. Ann., XLII, p. 18, 1891), that a sodium flame is a better electrolytic conductor in virtue of the solution of sodium, there is some doubt in my mind as to the sufficiency of Giese's result for V. Helmholtz's purposes.

but as a rule the transition is smoky and peculiarly indefinable. The chief experimental advantage of this arrangement is the occurrence of a jet of a decidedly lower temperature than the pure steam jet. The quantitative value of such a comparison is obvious. If a jet with but one hole, 0.15 cm. in diameter, be compared with a jet containing a number of holes of the same size (differential apparatus, other things equal), and if pressure is continually increased, the latter will reach the opaque field sooner than the single-holed jet. After this the action is reversed, so that the single jet reaches the initial orange sooner than the other, if the other passes beyond opaque at all. When there are more holes than one, the faint colors of the second order are more obvious (as might be supposed), and a peculiar feature is the persistence of intense emerald greens. If the jet contains as many as five holes, the colors become dull. The same dullness is observed for a single jet when the air hole *C* fig. 14, is partially stopped up. (Cf. sections 14, 15.) These experiments have an important bearing on the theory of the condensation process.

Corresponding experiments were made with long tubes, using a single jet. Thus I found, by decreasing the length gradually from 220 cm. to 150 cm., that for all jet intensities the field remains opaque. On further decreasing the length the colors gradually appear, but even at 110 cm. they are dull. Tubes of this kind are serviceable for bringing out the green and green yellow near the beginning of the third order of colors. Section 18.

The temperature of the walls of the color tube does not seem to produce a marked result. Thus I put a wide helix of lead pipe, through which cold water was flowing, into the color tube, fig. 8, but obtained no noteworthy effect beyond a certain loss by condensation. The differential apparatus was not tested in this way.

Fumes of naphthalene, camphor, alcohol, ether, turpentine, etc., when pure, showed no dustlike action. A space filled with naphthalene fumes is rather cleansed of active dust, and I suspect that this action is connected with the formation of little crystals. For purposes like the present, therefore, air in which naphthalene fumes have condensed may possibly be used for filtered air with advantage.

Sulphur chloride (which is decomposed by water liberating sulphur) acts as actively as sulphuric acid.

The action of sulphur itself is more interesting. The effect of the flame has already been described in section 18. Let the flame be extinguished and the sulphur cooled down to the point of incipient freezing—i. e., until the appearance of the surface changes from glossy brown to opaque yellow. On bringing this sample near the air hole *C* of the differential apparatus, the field at once clouds over, even if the influx pipe is above 2 meters long. As the sulphur solidifies further, the series of colors is slowly run through. This experiment might serve to illustrate the difference of vapor tension at the solid and

liquid surfaces of the same substance, at the same temperature (Ramsay and Young, Fischer). Furthermore, a stick of sulphur softened in a burner suggests itself as a convenient method of showing the succession of colors described in the above table.

As compared with moist air, dry air must be the better dust carrier, for the particles are not clogged with moisture. The surmise is reasonable, moreover, that a dried particle may be peculiarly effective. Experiments made with air passed over chloride of calcium and phosphorus pentoxide negated this. These bodies are neutral. Hence, in the case of sulphuric acid, it is actually the vapor which is the active principle, unless, indeed, an air ammoniac sulphate be produced.

By far the best dust producer which I have found is a freshly-cut surface of phosphorus at ordinary temperatures; and its activity persists for a long time (certainly many hours) after cutting. The fingers rubbed with such phosphorus are also active. If air aspirated over a piece of phosphorus as big as a pea be mixed with different quantities of room air (coalescence of the conveyance tubes), persistent colors correspond to each degree of mixture, and they may thus be produced at the minimum (all but vanishing) steam pressure. The active agent here is the invisible dust of oxidation; for ozone, according to Mascart, is inactive.

It is important to notice that the yellows of the first order are not affected by dust—another argument in favor of their origin from exceptionally small water globules.

To the effect of the temperature of the air into which the steam is discharged, I shall devote the next chapter. Suffice it here to say that below 9° C. the field is opaque at all pressures. As temperature increases, the steam pressure at which the blue of the first order passes into opaque increases from zero rapidly to a maximum; whereas the pressure at which the yellows of the first order pass into opaque decreases from an enormous value, at even a more rapid numerical rate than before, to a minimum, in such a way that, for normally dusty air, the said maximum and minimum coincide at about 40 cm. of mercury (pressure) and 35° C. Here, therefore, the blue passes into the yellow without an opaque demarcation. Beyond this (air temperature increasing) the colors, which have gradually grown fainter, vanish. The tube is clear and colorless, showing that the supersaturation at the jet is nil.

26. Electric excitation.—Von Helmholtz, in his paper on the electrification of jets, leaves the question as to the cause of the phenomenon open, indicating that either the solid matter thrown off from the highly charged point or the diffused ions may be the active agent. His attitude as regards these two hypotheses (both of which he examines elaborately) has virtually been given in section 24, *mutatis-mutandis*.

Mr. Aitken throws himself vigorously into his own modification of Bidwell's hypothesis, as already stated in section 11. Aitken supposes that the comminution of drops, necessary to produce an opaque jet, is

here maintained in virtue of their electric charges, since the repulsions thus set in action prevent a coalescence of drops. It is noteworthy that no effect is produced unless the exciting electric charge escapes from a point, so that high potential is essential.

Now, I was somewhat surprised to find an observer of Mr. Aitken's acuteness entirely ignoring the misgivings of his predecessor, and particularly so since the recent experiments of Crookes on electric evaporation might well have emphasized the need of such precautions as v. Helmholtz took. For if there be any solid matter escaping from an electric point, the whole argument in favor of a truly electric condensation in steam jets is vitiated.

I made this test experiment: In the apparatus, fig. 8, the jet j is in the inside of a practically closed conductor. Hence it will not be acted on by an electric field on the outside of the apparatus. To give further assurance that this was the case, the (only) open air tube f was prolonged even 2 meters or more. I then caused the spark of a Ruhmkorff coil to pass across a gap made by two copper needles lying in the same line, with their sharp ends about a centimeter apart. Whenever this arrangement was brought near the open end of f (supposing the apparatus in action) the blue-gray field became opaque. Something, therefore, passed between the points of the spark gap, whether metallic dust or other material, which was simply sucked into f by the draft, and which affected the jet precisely as a bit of glowing punk would have done. I then adjusted the inductor so that sparks passed at the coil only, and none were visible at the portable spark gap. On again bringing the latter near the open end of f , the darkening of the field was evident enough, though not so intense as in the previous case. Even a silent discharge is therefore active.

The same results were obtained with a clean platinum spark gap.

This experiment may be made more beautifully with the differential apparatus, fig. 11. Connect the air hole C of the color tube $A A$ with an equally wide tube running vertically upward about 2 meters or more away from the jet. Then fix the spark gap in front of the open (upper) end of this auxiliary tube. The key of the induction coil may be held in the hand. Let the initial field of both $A A$ and $A^1 A^1$ be faint violet (say) of the second order. Then, as long as sparks pass across the gap, the field of $A A$ turns deep blue or opaque; or, in general, changes in color in the direction from the second to the first order, as the spark gap widens. Indeed, it is possible to obtain almost any of the colors with very little steam, quite permanently in this way, by simply regulating the spark lengths. The field of $A^1 A^1$ does not change in color. Silent discharges, (i. e., mere alternate chargings without sparks) act definitely but with less intensity.

Hence I conclude that the electrification of a jet by means of a point is at most a complex phenomenon. Although the effect of an electrical field on water jets is beyond question, no unassailable experiment has yet been made to exhibit the occurrence of a similar truly electric effect

in the case of the cloudy condensation in steam jets. And since only that part of the efflux which lies near the nozzle is influenced, the clear case in favor of the promotion of cloudy condensation by electrification as such is yet to be made. My own belief is that the evidence¹ will not be forthcoming, for reasons set forth in section 27.

I may note, in passing, that in the present experiments (spark lengths increased) augmentation of the number of dust particles produces the same result as did the increased supersaturation in the earlier work. A similar test may be made by holding the mouth of a sulphuric-acid bottle (or hot sulphur, etc.) near the open end of the air tube *C* and then gradually withdrawing the bottle. The field will be found to run through the gamut of colors from opaque to the second order. I accentuate these observations because of their theoretical importance (section 27), remembering that the field at the outset (before adding dust) was pale violet or indigo of the second order and the jet nearly shut off. Thus with little supersaturation the appearance of intense colors and smaller particles is somewhat startling. In no case have I in this way been able to produce the yellows and browns of the first order beyond the opaque, except by using phosphorus or the flame of sulphur. Here, however, heat enters as a factor.

One would expect the particles of the steam jet to be electrically charged, for the reasons given in Faraday's classical researches. I thought it worth while to test the case for a metallic jet, however, as follows: The brass nozzle was electrically connected with the earth and the charge of the jet collected by allowing it to play against an insulated metallic brush communicating with a Mascart electrometer. Producing a blue-gray field in one tube of the differential apparatus, I found that a maximum voltage of +10 was easily collected at the free jet of the other. This maximum increases and decreases markedly with the intensity of the jet. The positive charge is also decreased whenever a drop squirts from the nozzle. No difference between the maximum voltage of an opaque (sulphur) and an ordinary jet (cat. par.) could be detected; but I do not consider my experiments final.

27. Conclusion.²—In the above pages I have endeavored to show that a solution of the condensation problem may be regarded as hopeful for a certain class of water globules ranging in size from somewhat less than the sodium wave length of light to about one-tenth of this magnitude; in other words, the growth of the globule, from the latter to the former of these dimensions, can be controlled and studied. For particles smaller and particles larger than the limits given, the method (at its present stage of development) fails. Very frequently, however, laws carefully scrutinized within a given range suggest the behavior within the next range (as I will presently show), or else the method of the one

¹See reference to E. Kaiser in section 11.

²Reference to Hertz, Von Bezold, and other allied researches (see Professor Abbe's collection in Smithsonian Mis. Col., Washington, 1891), will be duly made in my future work. The present paragraph is a mere outline.

case leads to modifications of method for the other. If 0.000,030 cm. be taken as the limit of microscopic separation, then particles whose size is just exceeding the limit of interference measurement (0.000,040 cm. being the green of the second order and the above apparatus) are just becoming microscopically measurable. The problem thus begins to deal with something decidedly more tangible.

In conclusion, I have to advert more definitely to the point of view taken in Chapter I, trusting that the intervening paragraphs have shown the need of a more detailed knowledge of the true isothermals for the change of state-gas liquid. By the term true isothermals, I wish to indicate that the behavior of a free fluid is meant—i. e., one in which there is neither nuclear nor surface condensation, or virtually a dust-free fluid in a vessel of extensible and absolutely neutral walls. No such vessel exists; hence all the experiments must be of an instantaneous kind, so that the results may be noted before the vessel has time to distort them.

Necessarily the isothermals¹ for this ideal case must be of fundamental importance. Their chief feature may be already inferred. Near the region of changes of state all are characterized by a pronounced volume lag, in virtue of which at a given temperature it takes a higher pressure to change the pure dry vapor back to the liquid state than the pressure at which the liquid just wholly vaporized.

To take a concrete example, let the volume of a given mass of water at 100° C. be allowed to expand isothermally until the whole bulk is quite converted into dry steam. The pressure so obtained is the vapor tension of water at 100°—i. e., 1 atmosphere. Then if the vapor be dust free and contained in the ideal vessel, no condensation can take place on again decreasing the volume isothermally, at 100, until the pressure has reached a remarkably high value. For by hypothesis the only nuclei present must be a collection of water-vapor molecules and must therefore be of molecular dimensions. Hence the condensation pressure must reach the vapor tension at 100° C., at an extremely convex surface. It is interesting to estimate in a rough way about how large this pressure will be. The distance between the centers of two adjacent water molecules is probably greater than 0.000,000,01 cm., and probably less than 0.000,000,1 cm. At 100° the density of dry steam is (say) 0.0006 and of water 0.96. Finally, the surface tension of water in contact with air is at 20°, 80 dynes per linear centimeter. At 100° and in contact with steam the surface tension will be considerably less than this, but the datum given may be temporarily admitted. Hence the excess of vapor tension at a convex (molecular) surface of the diameter 0.000,000,01 cm. is 20 atmospheres, and the corresponding excess at a convex (molecular) surface of the diameter 0.000,000,1 cm. is 2 atmos-

¹It is customary to represent the volume of a given mass of fluid as depending on pressure and on temperature conjointly, and convenient for the time being to consider either temperature constant (isothermals) or else to consider pressure constant (isopiestic).

pheres. One should, therefore, be prepared to exert about 10 atmospheres, in order to condense¹ pure dust-free dry steam at 100° C. in an ideal vessel of the kind in question. When the necessary pressure has been brought to bear, the steam would collapse as a whole, supposing, of course, that temperature never exceeds 100° C.

If, instead of pure steam, a mixture of dust-free air and dry steam be given, the phenomenon, in its general features, would retain the character just sketched; for here also there is an absence of other than molecular nuclei. In one respect, however, a difference is manifest—when the condensation pressure is exceeded, the steam would not condense out of air, as a whole, for the case is now virtually one of solution. In other words, the interaction of air and steam is brought into play and successively increasing pressures correspond to successive states of chemical equilibrium. (Cf. Chapter I for the analogous case of liquid solutions.)

This condition of things changes enormously when dust is introduced either into pure steam or into the air mixture. If the diameters of the dusty particles were only one hundred times as large as the smaller estimate of molecular diameter (10^{-8} cm.)—i. e., if the dust particles were only one-millionth of a centimeter thick—they would already reduce the condensation pressure to about 15 cm. of mercury. Dust particles, 1,000 molecular diameters in thickness, would reduce it to about 1 or 2 centimeters.² Moreover, the smaller of these particles (taking their density at about 2) would fall through air at the rate of less than 0.000,0006 cm. per second, and would be an integrant part of the air. Indeed, even the larger dust particles (0.000,010 cm. thick), falling at the rate of 0.000,06 cm. per second, could scarcely be separated except by filtration. The marked activity of very fine dust (section 24) is thus accounted for, and the term “dust-free” air is to be used with caution.

Instead of keeping temperature constant and studying volume in its dependence on pressure, the latter variable may be kept constant, and volume considered in its dependence on temperature.

¹I think the above experiment actually feasible, not isothermally, of course, but adiabatically. If it is performed it must lead to a superior limit of the absolute size of the molecule, either of liquid water or of any other liquid similarly treated. From this point of view such a research seems to me to be of unusual interest, and it may well be included as a part of my problem.

Again, in the case of freezing, the volume lag can actually be measured, as I showed in the *Am. Jour. of Sci.*, XLII, p. 125, 1891. In terms of Van't Hoff's analogy, volume lag expressed in atmospheres would be the increase of osmotic pressure at a convex molecular surface. Hence a reason is given by Thomson's equation for the undercooling of liquids, and the absolute molecular dimension of a solid molecule is defined in terms of known variables and the surface tension of the solid, a quantity which has already been recognized in Auerbach's researches on hardness (*Wied. Ann.*, XLIII, p. 61, 1891, Cf. p. 94). Thus a scheme for the absolute measurement of solid and liquid molecular dimensions is suggested.

²These numbers would be smaller if the temperature correction for surface tension were applied. These pressure differences or their equivalent temperatures are to be expected in steam jets.

The inferences are necessarily identical, remembering that an increase of pressure corresponds in its effects on volume to a decrease of temperature. Practically, the methods are more complicated. The only way of producing the condensation in question is some form of adiabatic cooling, so that pressure and temperature are varied simultaneously. But the effects may nevertheless be treated with reference to the elementary cases specified.

It is now in place to endeavor to apply these preliminaries to the actual case of the steam jet. I have worked this out at length, but, without more detailed experiments, I am loth to communicate it. A brief mention of the method pursued will here suffice. It consists essentially in a comparison of the vapor tension at the convex surface of the globule of water and that of the supersaturated steam immediately surrounding it.

If while the particle is growing there were no change of its temperature, nor the pressure of the surrounding medium, then the vapor tension at the convex surface would continually decrease as the size increases. Actually, however, the particle is being heated by the condensation of the water which promotes its growth. The case is therefore not excluded, that a particle increasing in size will show increasing vapor tension at its convex surface, more markedly so in proportion as the number of active dust particles per unit of volume is greater. But this is rather beyond the limits set for the present considerations. It is necessary, however, that at the outset the tension at the surface of the globule be virtually less than the tension of the supersaturated medium, supposing the phenomenon to be looked at by the above isothermal method.

Now the full growth of the particle is attained in an incredibly short space of time, probably in very much less than the hundredth of a second; whereas, when fully grown, it persists under the given conditions, without change of size, for an incredibly long time, certainly many seconds. Section 23. Hence the medium around the particle, losing volume in virtue of condensation, expands adiabatically.

Thus I derive two descriptive equations or curves, one expressing the tension at the surface of the particle in terms of its size, and the other the tension of the immediate neighborhood referred to the same size. If these curves did not intersect the particle would continue to grow forever. But if they do intersect, then there is a point at which the initially smaller vapor tension at the surface of the particle is equal to that of the immediate medium, and beyond which (size increasing) the vapor tension at the surface would exceed that of the medium. This point, therefore, fixes the dimension of the particle stable under the conditions for which the curves were drawn.

These principles contain an easy working hypothesis for the construction of a homogeneous theory of the above condensation phenomena. It therefore scarcely seems worth while to offer further comments until the whole question has been subjected quantitatively to a minute investigation.

CHAPTER III.

COLORED CLOUDY CONDENSATION AS DEPENDING ON AIR TEMPERATURE AND DUST CONTENTS, WITH A VIEW TO DUST COUNTING.

28. Introductory.—Mr. John Aitken, who has pioneered the meteorology of dust to a point of formidable importance, describes two distinct forms of apparatus for the quantitative measurement of the dust contents of atmospheric air. The first of these is his well-known “dust counter.”¹ It has been widely used, both by himself and others, and needs no comment here. Its trustworthiness seems assured, both in view of the elementary principles on which it is directly based and of the consistency of the results obtained. In one respect this dust counter is unique, for it probably takes account of all the particles, large or small, present in the given volume of air. At least it does not overlook the larger particles. In indirect dust counters (Mr. Aitken’s “koniscope” and the apparatus of the present paper being referred to) only a certain range of dimensions of water globules is visible, and it does not follow that all the dust present is contained in the optically active corpuscles. The restricted use of koniscopes is not necessarily a disadvantage; for the particles counted may be the very ones of interest. Indeed the whole question resolves itself into the character of the problem to be answered.

At the outset, therefore, it does not seem obvious that the indications of the two classes of instruments need necessarily be identical, and a calibration of one in terms of the other is to be made cautiously, so long as certain grades of dust are optically less active than others.

In the “koniscope” Mr. Aitken² has endeavored to express the dust contents of a given sample of air in terms of the color, or of the intensity of color, or of the amount of exhaustion necessary to produce a given color, when the cloudy condensation is produced by sudden expansion of the gas in a suitable tube, containing enough moisture to saturate the air. The importance of temperature is pointed out, but not evaluated. Mr. Aitken prefers to make the estimation in terms of the color intensity of the blue, and the apparatus is graduated by comparing it with the direct dust counter. Based as this apparatus is on

¹ Aitken: Trans. Roy. Soc. Edin., xxxv, part 1, 1888; *ibid.*, xxxvii, part 1, No. 3, 1892; Proc. Roy. Soc. Edin., xvi, p. 135, 1889 (containing full descriptions); *ibid.*, xviii, p. 259, 1890-91; Nature: xxxvii, p. 428, 1888; *ibid.*, xli, p. 394, 1890; *ibid.*, xliv, p. 279, 1891; *ibid.*, xlv, p. 299, 1892, and elsewhere.

² Aitken: Proc. Roy. Soc. Edin., li, p. 425, et seq., 1892.

color discriminations, it is not adapted to give more than a few steps of dustiness, and Mr. Aitken chiefly recommends it for qualitative purposes—such, for instance, as may present themselves in sanitary work.

29. *The present method.*—During the course of my experiments on the thermal distribution in steam jets, I had frequent occasion to note the actuating steam pressure at which the intense blue-violet field of my color tube merges into opaque, eventually to reappear (pressure increasing) as an orange-brown field of the first order. It struck me that here was a sufficiently sharp criterion for fixing a value of pressure depending in the given apparatus only on the temperature and the dust contents of the inflowing air. In other words, for a given kind of air and at a given temperature, there are two well-defined pressures at which color (blue and yellow) vanishes into blackness. If the kind of air remains the same while its temperature varies, the paired values of pressure will also vary markedly, so that the margins of the opaque field may be mapped out in a diagram in which pressure is expressed in its dependence on temperature. It is the chief purpose of the present paper to show the character of this diagram, and to indicate the manner in which the positions of the loci vary when the dust contents of the inflowing air are also varied. Incidentally I will endeavor to ascertain the more immediate cause of the opaque field, and to see whether the water molecules may not themselves become nuclei of condensation. Section 42.

30. *Color apparatus.*—A full account of the necessary apparatus is given in fig. 14, where the color tube is shown at *A A*, and the method of varying the temperature and dustiness of the inflowing air is shown at *E, D, F*. The color tube is identical in form with the apparatus described in Chapter II, section 15.¹ I need only to call to mind here that the steam issues at the jet *j*, from a nozzle about 0.16 cm. (one-sixteenth of an inch) in diameter, and that the tube *A A* is about 50 to 60 cm. long, and, in common with the air hole *C*, about 5 cm. (2 inches) in diameter. The glass plates *g* and *a* are kept clear by moistening with a solution of caustic potash, and the mirror *M* reflects sky light through the tube. Mixed steam and air escape at *B*, and provision is made (not shown) for screening off extraneous light from *g*, the window through which the color observations are made.

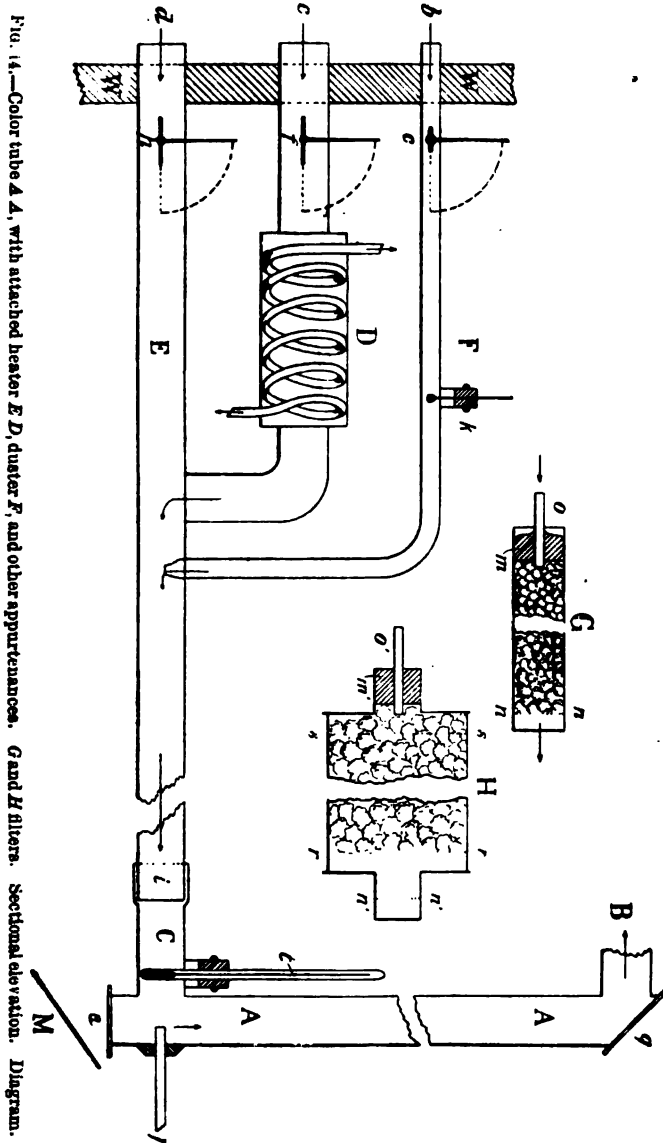
The two essential appurtenances are the thermometer *t*, to register the temperature of the inflowing air at *C*, and the open mercury manometer (not shown), by which the pressure of the steam entering the jet *j* is measured. Inasmuch as a mercury thermometer is not very quick in its indications, the air at a given temperature must be allowed to pass over the bulb of *t* for some time before the record is taken.

The steam used was generated in a copper globe about 25 cm. in diameter and provided with a water gauge and a steam gauge. The

¹ Barus: *Am. Meteo. Jour.*, IX, p. 488, 1893.

vessel is heated by a large ring burner¹ and is strong enough to withstand, say, 10 atmospheres, though in the present work pressures below 2 atmospheres fully suffice.

G and *H* are forms of air filters, to be described in section 41.



31. Influx tubes.—The air entering *C* is taken out of the atmosphere, the three influx tubes *E*, *D*, *F* passing through the window frame

¹ This apparatus used for other purposes is shown in Bulletin United States Geological Survey, No. 54, p. 60, 1889.

W W and opening into the air on the outside, as shown at *b, c, d*. Valves are inserted into each of these tubes at *e, f, h*, so that the quantity of air passing through any one of them may be regulated or even quite shut off. In the winter, when the valves are open, the air rushes through the tubes with considerable velocity, even when the jet *j* is not in action. This velocity increases with the steam pressure actuating the jet, but can be regulated by shutting off the valves *e, f, h* partially.

The tube *E* is clear, and the air passing through it has the temperature of the atmosphere. The tube *D* discharges into *E* and is provided with a drum, containing a coil of thin lead pipe of about 0.6 cm. (one-fourth inch) caliber. About twenty turns of pipe, each somewhat less than 5 cm. in diameter, in a drum 35 cm. long and somewhat less than 10 cm. in diameter, are more than sufficient. In the winter time steam is passed through the lead pipe. Hence by suitably regulating the valves *h* and *f*, the air flowing through *C* may be kept at any desirable temperature; and, as temperatures between 9° and 40° only are needed for the present purposes, this arrangement is quite satisfactory. In the summer time chilled brine or an expanding gas circulating through the coil will probably be serviceable.

The tube *F* also discharges into *E*, and is useful for increasing the dust contents of the air entering *C*. For this purpose a little closed basket of wire gauze attached to a wire passing through a perforated cork, is inserted into the aperture *k*, as shown in the figure. A piece of phosphorus is put into the basket. The dusty exhalation of a freshly cut surface of phosphorus is almost nil at 0° C., but increases with great rapidity when the temperature rises. Section 11. At any given temperature above 15° its dust supply is nearly constant for a long period of time (hours); hence its availability in the present work, unless the weather is very cold. Fortunately cold temperatures can usually be dispensed with when artificially dusty air is examined.

It is to be noted that all the tubes *E, D, F* must pass out of the room. If, for instance, *b* opened into the room (which would often be desirable, for the reasons just mentioned), then, if the jet is not in action or only slightly in action, cold air would pass into *C* and *D* and out at *b* as well as at *B* into the room. At low steam pressure the flow of dusty air would, therefore, necessarily be irregular. An advantage is secured by making the common tube *C* long, so that the air may be well mixed before impinging upon the jet. At best, however, air dusted in this way is an inferior substitute for atmospheric air, and the results show much more fluctuation. Each of the valves, *h, f, e* is provided with a suitable dial and an index. The valve *e* must be free from leaks. It is best, moreover, when atmospheric air is examined, to remove the basket *k* altogether, and to close the hole with a cork. The hole through which *F* discharges into *E* need not be more than 0.5 cm. (one-fourth inch, say) in diameter, and it is advisable to carry it into

the axis of E by aid of a glass tube. The whole train of tubes is easily made of ordinary tinned drain pipe and suitable elbows. To summarize, the faint phosphorescent glow visible on phosphorus in the dark is a nearly permanent dust producer. This phosphorus-tainted air, discharged through a one-fourth inch to one-eighth inch tube into the 2-inch tube of pure air, usually produces persistent color effects at ordinary temperatures. Thus the dilution is less than one one-hundredth.

32. Errors.—A few remarks on the shortcomings of the apparatus may be made here. It is clear, in the first place, that the temperature of the air entering C will vary with the intensity of the jet—i. e., the velocity of current—even if the other adjustments remain unaltered; for the more rapidly the air passes through the drum D the less it is heated. This, however, is no serious inconvenience since temperature is measured at t .

Similarly the amount of dust introduced into the air will (probably) depend on the rate at which the current passes the basket at k . Hence at great jet intensities the air will be less dusty than for small intensities. I have found no easy way by which this discrepancy can be evaluated, and my experiments with artificially dusted air are intended rather to show the character of the dust variation than to map out precise loci. Sections 38–40. Fortunately the dust effect is so striking that there is no possibility of misinterpretation. Experiments which I made by introducing dust with jet pumps and aspirators showed no advantages. To vary the dust contents uniformly at all jet pressures the mouths c , d of the air tubes must be introduced into a large artificially dusted room, instead of the atmosphere. But this method also presents grave difficulties. The final resort seems to be to examine the atmosphere at different times and in different places, or to construct apparatus for the rapid filtration of air. Sections 41, 42.

One serious theoretical question may be referred to here. It is necessary that at all steam pressures the amount of air entering C should be nearly proportioned to the amount of issuing steam. No doubt this is nearly the case; for not only do the air and steam currents increase and decrease together, but the air is admitted in excess of the quantity necessary to produce condensation at the supersaturated parts of the jet, and it is to this condensation that the color indications apply. If the valve e be closed and the valves f and h all but closed, the pressures at which the margin of the opaque zone appears from blue increases; but the temperature registered at t also increases at even a greater relative rate, so that the apparent effect is curiously enough rather an excess than a deficiency of dust. Section 40.

I infer from this that in the work below the air is always admitted in quantity sufficient to produce its maximum dust effect. To test this question preliminarily, I replaced the 0.16 cm. nozzle by another 0.09 cm. in diameter, and thus (cet. par.) only discharging one-third as

much steam as the former. The new results virtually coincided with the old (section 42); and hence, though the relations below were obtained from a given apparatus, they are probably true generally¹ so long as the inflowing air exceeds a certain minimum quantity. A full discussion of all these points will be in order after the laws relating to steam pressure, air temperature, and color have been fully exhibited. I will then show (sections 44-45) to what extent each jet pos-

sesses special hydraulic properties, depending on the degree of smoothness of bore.

The fact that pin-hole jets are quite sufficient makes the practical construction of the apparatus, fig. 14, on a small scale an easy possibility. A globular copper boiler 5 inches in diameter, and a sensitive steam gauge with a capacity of less than 15 pounds, are available for generating the steam and recording pressure.

33. Results. Normal atmosphere.—The results in hand are necessarily in very great number, for the case is one in which the observer has to construct the mean value or path, when the observations themselves are unavoidably discrepant. It will, therefore, be expedient to avoid cumbersome tables, by expressing all the data graphically. An ulterior advantage is gained in this way, inasmuch as the broad features of the phenomena are at once evident to the eye.

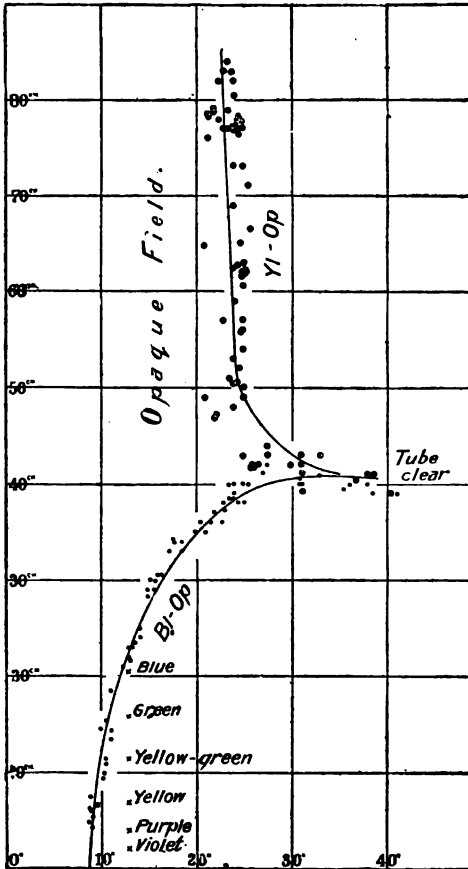


FIG. 15.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

In the chart, fig. 15 (and in all succeeding charts), the abscissas indicate the temperature, in degrees C., of the air entering the color tube at *C* (fig. 14); or, in other words, the registry of the thermometer *t*. The ordinates show the pressures in cm. of mercury under which the steam is forced out of the jet. The

¹It will be expedient to consider the small differential effect of variations of the barometer, and the tendency of the pressure (blue opaque) to fall with the time of efflux, elsewhere.

points of the curve between 0 and about 40 cm. then show the corresponding values of air temperature and steam pressure, at which the blue-violet (first order) field seen in the color tube merges into opaque. The points of the curve lying quite above 40 cm. show the conditions at which the brown yellows of the first order just emerge from the opaque. Curves indicating the approximate loci are drawn through the points.

Below about 9° C., therefore, the field is opaque at all pressures. Above 9° , the pressure at which blue changes into opaque rapidly increases with increasing temperature; and the pressure at which brown yellow changes to opaque decreases from an enormous value, and at even a more rapid rate, as temperature increases. Both loci, curving at a gradually retarded rate, eventually reach a common asymptote at about 41 cm. (temperature being indefinitely high). At the same time the colors which were very intense at the lower temperature gradually become fainter and the opaque zone more translucent, until, at about 40° of air temperature (depending on the size of the nozzle, section 42), the field is clear and without color. The escaping steam is gaseous and not visibly condensed. When temperature decreases again from 40° , white yellow is the first color to appear, showing that the particles here must be the smallest of the whole series. At 35° the change from faint yellowish tones to faint white blues, when pressure is made to vary suitably (see chart) from larger to smaller values, is quite marked. There is no opaque demarcation, however, but rather a mixture of colors, for the opaque field is hardly impervious to light above 30° . Indeed, one often notices a brownish field surrounding the jet, on a violet-bluish ground.

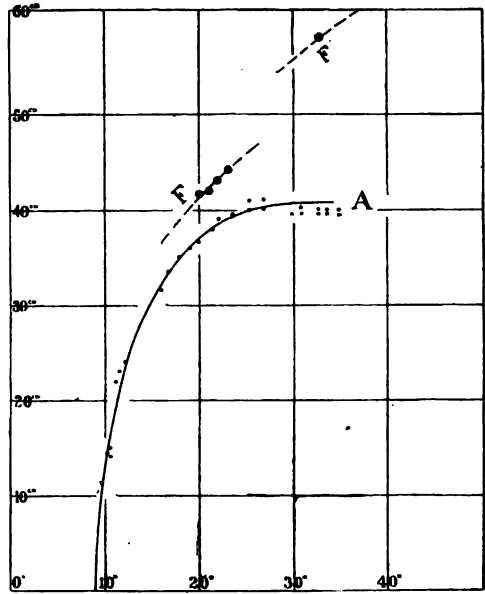


FIG. 16.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

At 35° the change from faint yellowish tones to faint white blues, when pressure is made to vary suitably (see chart) from larger to smaller values, is quite marked. There is no opaque demarcation, however, but rather a mixture of colors, for the opaque field is hardly impervious to light above 30° . Indeed, one often notices a brownish field surrounding the jet, on a violet-bluish ground.

For all temperatures and pressures lying to the left of the two curves the field is opaque, and it sends off a kind of cusp to penetrate into higher temperatures. There is a characteristic difference between the contours of the two margins; for, whereas yellow-opaque after a sharp inflection shoots up almost vertically, blue-opaque shows a regular change of curvature throughout.

At about 13° in the chart, I have inscribed the approximate positions of the successive interference colors,¹ indicating their positions by a cross. This can not be nearly so well done as the location of the opaque margin, and, as the colors are of smaller interest in the present chapter, I will not enter into the subject further. The contour of the successive color curves is easily surmised from the line for blue opaque. Similarly

above the yellow opaqueline, a family of browns, oranges, and yellows may be located.

When the dust contents are increased, the margin of the opaque field approaches the abscissa, and hence the color loci will be successively more crowded together.

In the chart, fig. 15, only a single air tube (*D*, fig. 14) was available. The air was heated to about 40° by the circulating steam. This was then shut off and the temperature and pressure at which the colors disappeared noted on cooling. The mercury thermometer is scarcely sensitive enough for such observations, and the temperatures of the diagram are probably too high. I have, therefore, lumped all my observations between February 10 and 23, 1893, in this chart, seeing that the phenomenon as a whole is well represented.

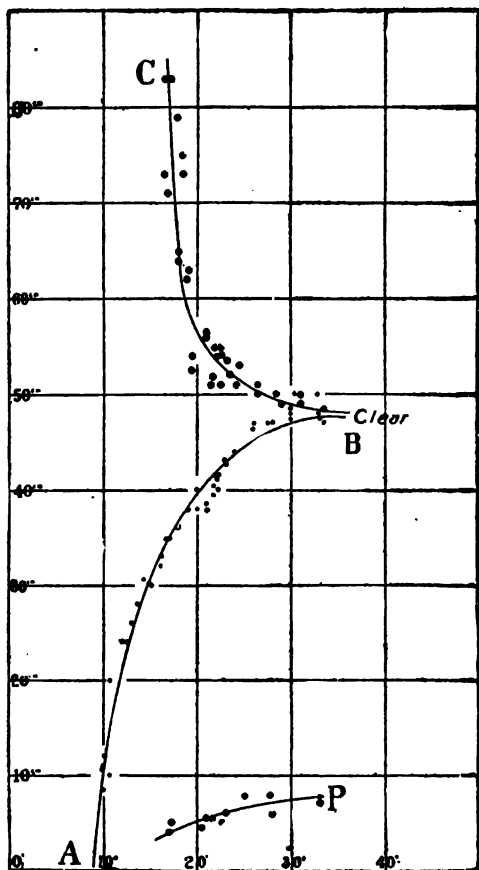


FIG. 17.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

with the phosphorus tube closed up and the phosphorus removed. Great care was taken to wait for stationary temperatures, and about five (or more) steps between 10° C. and 40° C. were selected for observation.

The first set of experiments was made on February 23, the chart,²

¹ See Chapter II, section 18.

² The observations *F F'* in fig. 16 refer to filtered air and will be described in section 41.

fig. 16, curve A being obtained in the morning and fig. 17 in the afternoon. The day was cold, with snow covering the ground. The blue-opaque curve A, fig. 16, virtually reproduces fig. 15; but the curve fig. 17 differs from it, inasmuch as the tangential angles in the latter case are steeper, so that the locus is less curved and rises higher than in figs. 15 or 16. In all cases yellow opaque lies above blue opaque. I was at first inclined to refer this to differences of the vanishing stand-

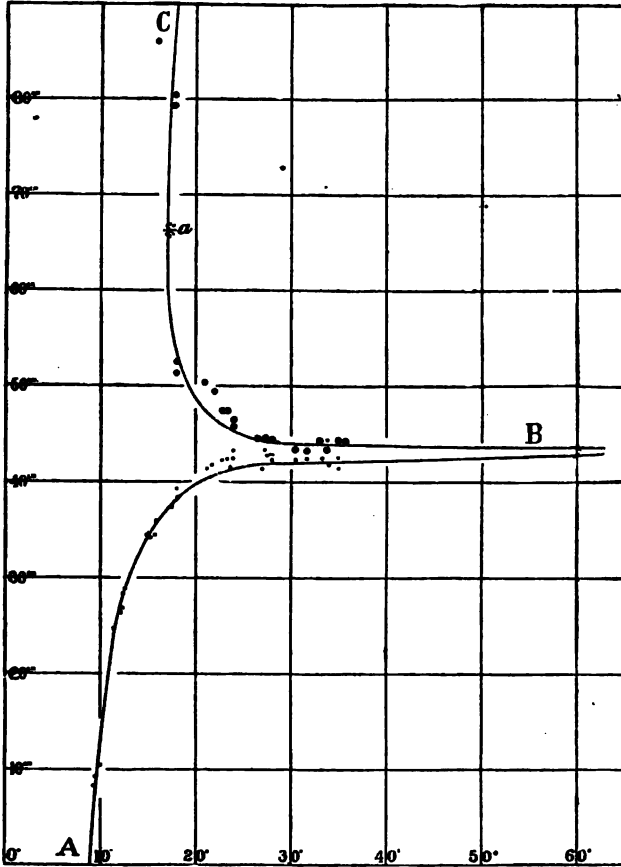


FIG. 18.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

ard, believing the two curves to contain consistent observations, but differing from each other for reasons purely subjective. Whether or not this is the case can only be found by comparison with succeeding series of observations, as will presently be seen. Taking the observations at their face value, the indication is less dust for the afternoon than for the morning. The curve P, found for artificially dusty air, will be described below. (Section 38.)

35. Further data.—The next series of observations were made on February 27 (cloudy), 28 (rain), and on March 2 (clear). There was but little difference in the respective loci of the data, except that on the latter day the asymptote was somewhat below the position for the other days (see chart, fig. 18). The common asymptote takes a mean position (pressure, $p = 43$ cm.) between the corresponding values of figs. 15 and 16 ($p = 42$ cm.) and fig. 17 ($p = 48$ cm.).

36. Further data.—On March 3, however (see fig. 19), the asymptote rose again to the value of about $p = 46$ cm. The data here are not quite so uniform as in figs. 15–18, but the locus is none the less outspoken. The weather was cloudy, antedating the storm of March 4. Two series

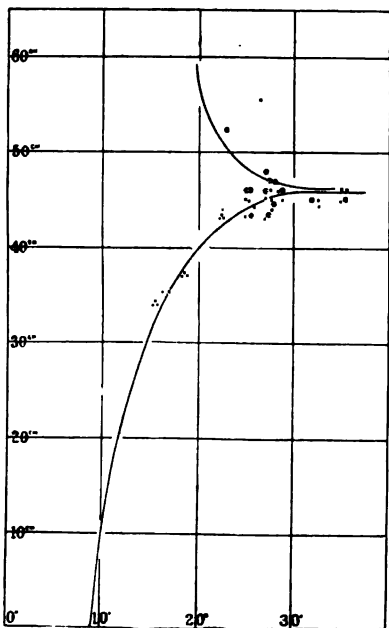


FIG. 19.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

of observations were made. The prevailing warm weather prevented my taking observations at low temperatures. These new results induced me to conclude that the observations of figs. 16 and 17 might very well correspond to different states of the atmosphere.

Finally, fig. 20 contains the results of March 6, 8, and 10, agreeing in character with fig. 18; while during the intermediate date, March 7, the locus fell to the lower position shown in fig. 21. These figures as a whole at least afford apparent evidence of the oscillation of the asymptote with the dust contents of atmospheric air. The observed interval of oscillation is within about 8 cm. of mercury pressure, but usually much below this.

37. General character of the loci.—

Resuming the remarks of section 33, it is seen that when the asymptotes

are high the loci as a whole show less curvature and the points between 20° and 30° C. tend to fall below the corresponding points for low asymptotes. I have endeavored to bring the whole phenomenon into a convenient equation, in which temperature and dust contents might appear as two variables by which the contours (pressure) of the margin of the opaque field (figs. 16 et seq.) are conditioned. The invention of a single form in which both the blue-opaque and the yellow-opaque margins are contained is more difficult than the fitting of a separate form for each curve, and possibly I have not been fully successful in any case. Cumbersome equations, or such as lead to involved computations, are of little interest for the present purposes, where the object

sought is merely a terse and convenient epitome of the very large number of isolated observations which go to make up each of the curves in question.

I will here omit the earlier hyperbolic and exponential forms, each of which brought out some particular feature of the curves, and merely state a general form which (all things considered) probably reproduces my results within the limits of error.

Let p be the steam pressure actuating the jet, and t the temperature of the air into which the jet is discharged, and let A, B, C, n be constants to be presently discussed. Then

$$t = A + 10 \frac{C p}{(p-B)^n} \dots (1)$$

The quantity $(p-B)$ in (1) is always to be taken as a numeric—i. e., positively—otherwise imaginary results are encountered. Suppose, now, this equation is tested by the data of fig. 18, as these fairly represent a mean case. Then

$p = 0, t = A = 9$, by observation;

$p = B, t = \infty$, or $B = 43$, the height of the asymptote above the abscissa;

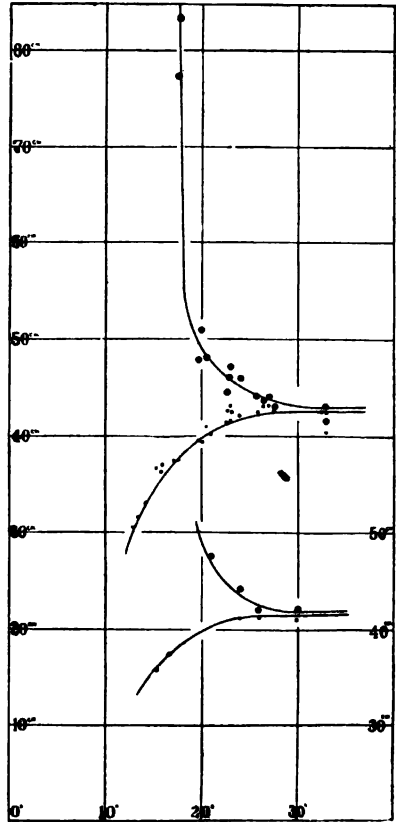
$p = \infty, t = \infty$.

Hence the yellow-opaque margin, lying quite above $p = B = 43$, corresponds directly to equation (1); whereas the blue opaque margin, lying quite below $p = B = 43$, corresponds to (1) with $(p-B)$ replaced by $(B-p)$. Furthermore, while in the yellow opaque branch p increases from 43 cm. to ∞ , t passes through a minimum value. It is therefore necessary to inquire the position and character of this singular point.

Let equation (1) be differentiated, remembering that $t = 0$ corresponds to $p = -\infty$, and therefore does not enter the present problem, and that $B = p$ has already been disposed of. Then the pressure p_m , corresponding to the minimum temperature t_m in question, is found to be

$$p_m = \frac{B}{1-n},$$

and the somewhat more involved expression of t_m is found from equation (1).



FIGS. 20 and 21.—Charts showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

With these preliminaries, the remaining constants C and n are then easily enough, though somewhat tediously, obtained from the observations making up fig. 18, by trial. The results are as follows:

TABLE 4.— *Computed margin of the opaque field.* $t = A 10^{\frac{C p}{(p-B)^n}}$

$$A = 9; C = 0.013; n = 0.35; B = 43.$$

[Steam-pressures, p , in centimeters of mercury; air temperatures, t , in degrees C.]

Blue opaque.		Yellow opaque.	
$p = 0$ cm.	$t = 0.0^\circ$	$p = 43$ cm.	$t = +\infty$
10	9.8	44	38.6
20	11.0	47	21.4
30	13.0	50	19.2
40	20.3	66.2	17.4
42	31.6	70	17.4
42.8	85.3	90	18.1
43	$+\infty$		

¹ Minimum.

This curve, equation (1), has been inscribed in fig. 18, to show the grouping of the observations around it. The minimum is marked at a ($t_m = 17.4^\circ\text{C.}$, $p_m = 66.2$ cm.). Throughout the extent of the figure it unites two sufficiently flat curves to fairly represent the observations; for this part of the margin, from its exceedingly steep ascent, can not be traced with precision.

As a whole, therefore, equation (1) has reproduced the complete phenomenon surprisingly well, both as regards the blue opaque ($A B$) and the yellow opaque ($B C$) margin of the opaque field. No doubt better agreement could be had on further trial, particularly by varying the point of intersection with the abscissa $t = A$. I shall not, however, do this here, since in the present paper the chief datum is the height of the common asymptote ($p = B$) above the abscissa. It is this parameter which expresses the dust contents of the air, and which fortunately may be obtained without computation by the direct observations presently to be more fully specified.

38. Artificially dusty atmospheres.—To interpret the above data it is necessary to increase the dust contents of the normal atmosphere artificially, utilizing the tube F , fig. 14, containing phosphorus. The results for this case are not without complexity, but the character of the effect produced is obvious at once—it takes but a trace of phosphorus-tainted air to make the field permanently opaque at all pressures and temperatures not unreasonably high. In other words, the tendency is to drop the blue-opaque curve of the above figs. 15 to 21, into coincidence with the abscissa. One would surmise that at least the asymptotic portion of the yellow-opaque curve would likewise drop to the abscissa, and this is actually the case, as will be shown presently. By allowing the discharge from F to take place into E through a glass tube, only 0.6 cm. (less than one-fourth inch) in diameter, while the air

tube *C* is fully 2 inches in diameter, I was able to dust the air sufficiently to obtain at least the approximate contours of the corresponding relation of steam pressure and air temperature. The data are inscribed in fig. 17, and together they make up the curve *P* near the axis of temperature. Thus the striking potency of even traces of dust is well exhibited.

Clearly the rudimentary curve *P* is a member of the same family to which *A B* belongs, and it is therefore obvious that the whole vertical distance between *B* and the abscissa is a region of temperature and pressure loci, each of which corresponds to a particular value of dustiness. Since, therefore, the accuracy with which the point can be located at any (mean) temperature is about 1 cm., the apparatus ought to register about 40° of dust contents between normal atmospheric air and the artificial mixture stated. On this scale the variation of the dust contents of normal air lies in the interval between 40 cm. and 50 cm. of mercury, remembering that the height of the asymptote (virtually reached at 28° to 30°) is taken for registry.

39. Cold and warm phosphorus.—To bring out the conditions more fully, however, it is necessary to make supplementary tests both with phosphorus and with filtered air.

If the basket of phosphorus is placed in the tube *E* (fig. 14), near its mouth *d*, where the air temperature (in winter) is near the freezing point, no effect is produced. Thus at 21° to 22° the blue-opaque margin was at 41 to 42 cm., showing that the oxidation at zero is relatively negligible in spite of the current of air.

If, however, the same phosphorus be placed in the tube *EC*, at *i*, somewhere between the point of confluence and the color tube, and where the temperature is, say, 20°, then it is actually possible to obtain the yellow of the first order at steam pressures less than 1 cm. Thus at 19° the yellow-opaque margin was at 1.2 cm., and the color persisted with increasing brilliancy at all pressures above this.

For temperatures greater than 20°, the tube is yellow at all pressures, until eventually above 35° all color vanishes for want of super-saturation.

For temperatures below 20°, the tendency is to produce opaque fields. Thus at 15° the tube is opaque at all pressures above a few millimeters.

The explanation of this somewhat puzzling behavior is this: At any given admissible temperature the effect of phosphorous dust is a change of the color of the field in the direction from blue through opaque to yellow in proportion as more dust is added. Again, the dust contents of the air passing over a given lump of phosphorus decreases both with the rapidity of the current and with the degree of cold. Hence at higher temperatures than 20° brilliant brown-yellow fields are the usual occurrence when the phosphorus lies in the air tube *C*. If withdrawn from the air tube and so circumstanced that its exhalation is diluted with much air (tube *F*, fig. 14), then any color may be produced, depending on the degree of dilution. On the other hand, below 20° the

oxidation takes place more and more slowly, so that only very gentle currents of air can carry off enough dust to produce a yellow field. For strong currents in *C* there is a double source of dilution, and opaque fields are the rule. In other words, the air now approaches the state *A B* in fig. 17, so far as dust contents are concerned.

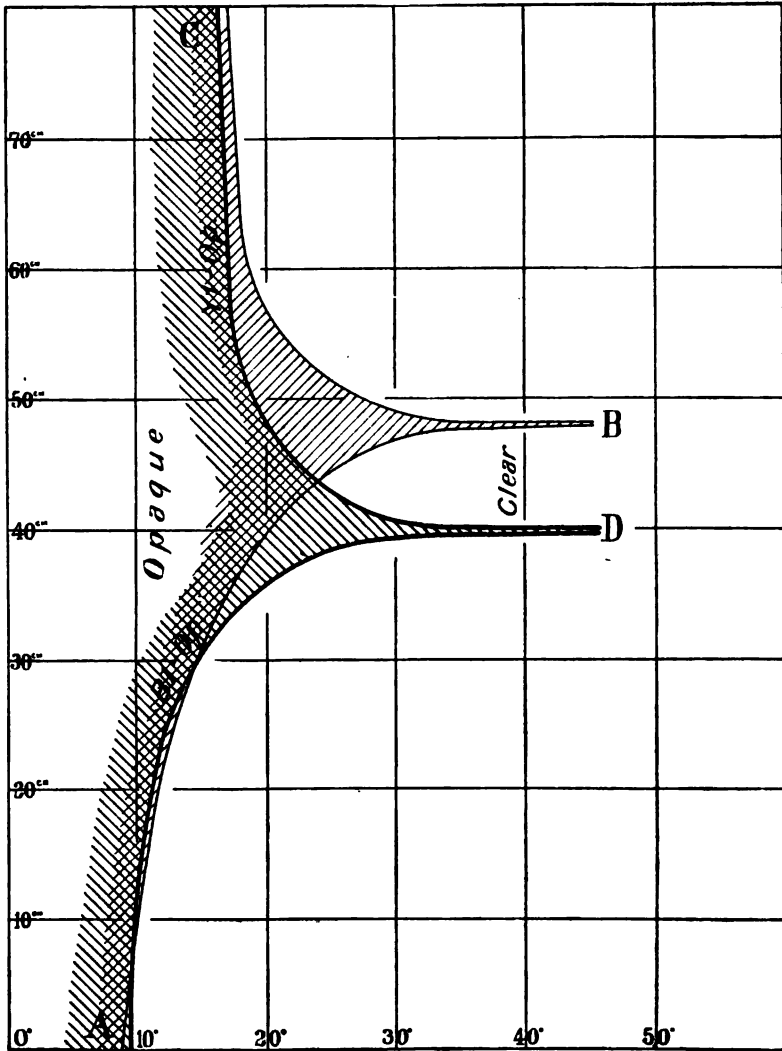


FIG. 22.—Variation of the opaque margin due to a change of dust contents. Diagram.

I have entered this subject at length because of its important theoretical bearing, seeing that it is necessary to disentangle a series of involved relations.

40. Effect of dust contents.—In fig. 22 (diagram), the pair of curves *A B C* indicates the margin of the opaque field for unusually pure atmospheric air. Above the horizontal asymptote through *B* there is a

symmetrical disposition of browns, oranges, and yellows, the order of colors decreasing upward. Below B the colors are blues, greens, and hues of higher orders. The whole field to the right of $A B C$ is colored merging into colorless; the field to the left of $A B C$ is opaque.

As the air becomes more and more dust laden the yellow territory encroaches on the blue, so that for unusually dusty atmospheric air the pair of curves $A B C$ has changed into $A D C$.

In the same way the yellows will continue to advance upon the blues for each successive (now artificial) increment of the dust contents of the air, until eventually the blues have been quite crowded out of the field and the whole territory is persistently yellow at all temperatures and pressures. In other words, the asymptote of the curve descends with increasing dust contents, while at the same time the curve $B C$ moves bodily to the right, so that $B C$ finally coincides with the coordinate axes of pressure and temperature. This at least is the essential feature of the phenomenon so far as I now understand it. Subsidiary details will be brought forward at some other time.

It is to be remembered that the particular curves, figs. 15 et seq., apply primarily to the particular jet discharging into the given tubes. Nor can any attempt as yet be made to graduate the apparatus; for a comparison with the Aitken dust counter (as has already been stated) is not legitimate, unless it can be proven that any given class of particles occurs proportionally to the total number—certainly a hazardous hypothesis. For the present the height of the curve above 28° (asymptote), expressed in centimeters of mercury pressure, is the empiric dust indicator.

41. Filtered air. Small apparatus.—A grave difficulty is encountered in using filtered air, inasmuch as the supply can not be obtained in sufficient quantity without employing very cumbersome apparatus. I have helped myself provisionally by using a tin tube G , fig. 14, with the end $n n$ large enough to fit snugly into the air hole C when the heater is removed. G is filled with cotton throughout about 20 cm. of its length in the usual way. The end $n n$ is closed with a sieve of brass-wire gauze, while the end m is closed with a perforated rubber cork, through which an influx tubulure, o , projects. This is connected with an ordinary oxygen tank, containing highly compressed air.

When the tube C (fig. 14) is closed with the filter G (no gas passing through it), the field of $A A$ at once becomes clear. At the same time, however, its temperature rises to the boiling point, and the absence of color in this case is as much the result of insufficient supersaturation as of absence of dust. Now let the compressed air be admitted, so that the tube $A A$ is considerably cooled. If the steam pressure is high enough, and the gas in sufficient quantity, the field first clouds over and then turns quite opaque. Thus, at a pressure of 50 cm. and a temperature registered at t of 47° , such a result (opaqueness) was obtained. At 30 cm. steam pressure the field turned cloudy, but

opaque; at 15 cm. no clouding was even apparent. Colors were not observed in any case.

In view of the insufficient air supply obtained in case of the filter *G*, I replaced it by the form *H*, differing from *G* in having a drum much larger in diameter (length 25 cm., diameter 15 cm.), and special sieves *rr* and *ss*. Similar parts are similarly lettered. Under like conditions, such a filter should supply nine or more times as much air as the other (*G*).

The absorbent cotton inserted between the sieves *ss* and *rr* (the former and the lid being removed and the latter [*rr*] soldered in place) was carefully laid in layers parallel to *rr*, quite filling the width of the drum. When full to the top, the cotton was compressed by the second seive *ss*, which thereafter was also soldered in place, the lid with the inlet pipe *o' m* soldered on, and the space between lid and *ss* filled with loose cotton to catch dirt. The compressed charge between *ss* and *rr* mainly acts as the filter. When not in use it was heated, so as to be thoroughly dry.

In the first experiments with the filter *H*, compressed air (issuing as usual from a narrow pipe, and at a tank pressure of about 15 atmospheres) was used as before. Spreading through the filter, the air enters the color tube at a much reduced velocity. As the air in the tank is gradually freed from dust by the subsidence of the latter, there is here an addition means of purification. But the method is much too lavish to be practical, even if it be conceded that the filter is actually efficient. The following data were thus obtained at temperatures comparable with the values in the charts. Colors were not observed:

Temperature.....	20°	21°	22°	23°	33°	C.,
Pressure.....	41.5	42	43	44	58	Cm. Hg.

In the set of data for 20° to 23° the filter was not so well packed as at 33°. Observations were discontinued for want of gas. I have inserted these data in the chart, fig. 16, at *F* and *F'*. When taken together, they suggest a locus of the same nature as fig. 17—i. e., implying less curvature in proportion as the air is less dusty. Bearing this in mind, the margin of the opaque zone at 20° for filtered air is not as much above the atmospheric curve as one would anticipate. It follows that the size of the particles producing colored cloudy condensation in atmospheric air is not necessarily enormous when compared with molecular diameters, an inference which I have already drawn¹ both from the character of the color phenomena and from the conditions of condensation. Cf. Chapter II, sections 22, 27.

42. Filtered air. Large apparatus.—Having obtained these preliminary results, I attacked the subject on a much larger scale, using an apparatus very similar to fig. 14 (with the phosphorus tube removed), except that the air, instead of being taken out of the atmosphere at *c*

¹ Am. Meteo. Jour., IX, pp. 507, 519, 1893.

and d , passed at those points through two large filters of the type H , fig. 14. A large Root blower, actuated by a 1-horsepower gas engine, forced the air through the system.

Contrary to my expectations, this arrangement remained to the last utterly inefficient. When the blower acted under low pressures, the air entering the color tube was insufficient in quantity. For higher blower pressures and a more rapid current of air¹ the evidences of filtration were practically absent. It was easy to trace the increase of dust contents with the velocity of the current of nominally filtered air, even though high speeds were excluded by the nature of the case. The nozzle of the original steam jet being 0.16 cm. in diameter, I replaced it by a finer one, 0.09 cm. in diameter, but without advantage. It is noteworthy that for atmospheric air both these jets gave identical results as to the location of the opaque margin near the asymptote. The colors for the fine jet were fainter, and together with the opaque field vanished at a lower temperature, as one would suppose, seeing that only one-third as much steam is available in one case as in the other.

The best results for filtered air are, therefore, those of the preceding paragraph. A sufficient degree of supersaturation presupposed, in no case was there an absence of condensation, but, as I can not assert that the air used was rigorously pure, it does not follow that I have reached the conditions² under which the molecules themselves act as condensation nuclei. Were this the case, then the supersaturation at the lower margin of the opaque field, expressed either isothermally as pressure or isopiesticly as temperature, leads easily to the molecular dimension. For the margin in question is a locus at which the issuing steam condenses as a whole, or in which the vapor contains within itself the conditions of condensation.

43. Apparent variation of dust contents of normal air.—In conclusion I shall summarize my results for the observed changes of the dust contents of normal atmospheric air, expressing this datum by the height (steam pressure in cm. of mercury) of the asymptote of the margin of the opaque field, at a temperature near 30° C., of the inflowing air. The observations for earlier dates are necessarily somewhat crude and sporadic, for in work of this kind it is difficult to arrive at a fixed personal equation at once. The apparatus, moreover, was imperfect in one or more of its early details. The air taken in at the center of the Smithsonian Park is probably as normally atmospheric as can be had in Washington.

¹Compare this with the similar experiences of Mr. Aitken, in *Trans. Roy. Soc. Edin.*, xxxv, p. 11, et seq., 1888.

²The delicate question of purity comes into play in the other researches. Thus condensation apparently without nuclei was produced by Aitken (*Trans. Roy. Soc. Edin.*, xxxv, p. 16, 1888), using the expansion method. R. v. Helmholtz failed to obtain it for exhaustions up to one-half atmosphere (*Wied. Ann.*, xxvii, p. 521, 1886), whereas Aitken's exhaustions were only to three-fourths atmosphere (*loc. cit.*, p. 8.)

TABLE 5.—Dust contents on successive days—i. e., pressures actuating a steam jet discharged into normal air, between 28° and 32° , when the blue color field passes into opaque.

Date.	Pressure.	Date.	Pressure.	Date.	Pressure.
	<i>Cm. Hg.</i>		<i>Cm. Hg.</i>		<i>Cm. Hg.</i>
1893.		1893.		1893.	
Before February 23.....	40	March 10, p. m.....	42.5	March 18, a. m.....	42
February 23, p. m.....	48	March 11, a. m.....	42	March 18, p. m.....	41.5
February 24.....	43.5	March 11, p. m.....	42.5	March 19, a. m.....	42
February 25.....	43.5	March 12, a. m.....	42	March 20, a. m.....	42.5
February 27.....	43	March 13, a. m.....	43	March 20, p. m.....	42
February 28.....	43	March 13, p. m.....	43.5	March 21, a. m.....	42
March 2.....	43.5	March 14, a. m.....	43	March 21, p. m.....	42.5
March 3.....	46	March 14, p. m.....	42	March 22, a. m.....	41
March 6.....	42	March 15, a. m.....	42	March 22, p. m.....	42
March 7.....	42	March 16, a. m.....	43.5	March 23, a. m.....	41
March 8.....	43	March 16, p. m.....	43.5	March 24, a. m.....	40.5
March 10, a. m.....	43	March 17, a. m.....	43		

The results are shown graphically in fig. 23, where the dates are laid off as abscissas and the dust contents (expressed in pressures as above) as ordinates.

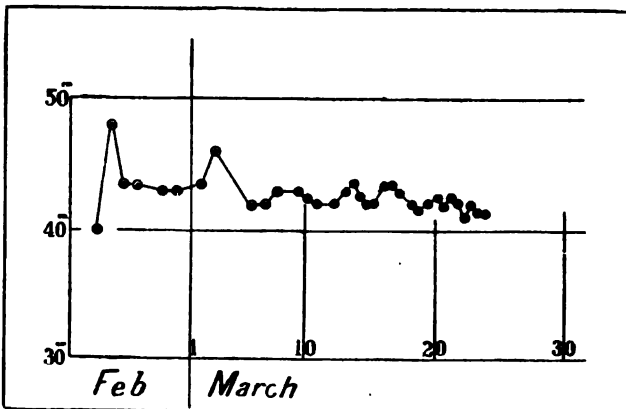


FIG. 23.—Diurnal variations of dust contents (empirically rated) of normal atmospheric air.

The chart contains about a month's observing, and in its general features calls to mind Mr. Aitken's "dust curves," remembering, however, that in fig. 23 the ordinates grow with increasing purity. Throughout the month the dust contents of the air do not depart very often from their normal value, and the fluctuations are usually characterized by a suddenness (relatively speaking) of appearance. Thus marked changes of dust contents may take place within fractions of a day. In general the air has been gradually getting less pure between February 23 and March 23.

I endeavored to put these data into correspondence with the meteorological elements of the time of observation, and I also availed myself of the comprehensive digest which my colleague, Prof. F. H. Bigelow, has constructed; but the time during which the above observations were taken is far too short to make such comparisons fruitful. The object of fig. 23 is therefore merely to exhibit the character of the results obtained

and the degree of efficiency of the above apparatus and not to attach any ulterior meaning to the results themselves. Section 47.

44. Continuation.—A similar series of observations made during the ensuing month is given in Table 6. During the first two weeks of this time the dust contents retain the degree of constancy as referred to in section 43, showing slight fluctuations around a mean value. After this (on April 6) the jet was used in certain experiments which kept it in action for about half a day. The table shows the effect of this treatment to be very marked and in the direction of an increase of apparent dust contents. The jet, moreover, never recovered its normal standard, proving clearly enough that the nozzle had in some way been permanently altered. Inasmuch, therefore, as an increased roughness of bore is equivalent in its relation to the jet to an increase of dust contents, the discrepancy observed can only be due to an appreciable amount of corrosion of the brass nozzle by the issuing steam. Thus a general inquiry as to the magnitude of the distortion which would follow from the use of improperly shaped nozzles was called for, and the investigation could now be made with considerable certainty, since the laws of the phenomena for a given jet were understood.

TABLE 6.—*Dust contents on successive days, etc.*

[Continuation of Table 5.]

Date.	Pressure.	Date.	Pressure.	Date.	Pressure.
	<i>Cm. Hg.</i>		<i>Cm. Hg.</i>		<i>Cm. Hg.</i>
1893.		1893.		1893.	
March 24, p. m.	40.5	March 30, p. m.	41	April 5, a. m.	41
March 25, a. m.	41	March 31, a. m.	41.5	April 5, p. m.	42
March 25, p. m.	41.5	March 31, p. m.	40.5	April 6, a. m.	41
March 26, m.	41	April 1, p. m.	40.5	April 6, p. m.	39
March 27, a. m.	40.5	April 2, p. m.	41	April 7, a. m.	39.5
March 28, p. m.	41	April 3, a. m.	42	April 7, p. m.	38.5
March 29, a. m.	42	April 4, a. m.	40.5	April 24, a. m.	38
March 29, p. m.	42	April 4, p. m.	40		

¹ After allowing steam to rush through the nozzle for half a day.

45. Bore of the nozzle.—In the experiments thus far, no particular mention has been made of the bore of the nozzle, excepting, perhaps, the few remarks (sections 32, 42) which refer in a casual way to dimensions. But the character of the bore is a datum of marked importance, and I have therefore spent much time in looking into the details of this question from the hydraulic point of view. With the aid of the koniscopic dust counter, just described, definite results may now be obtained by noting the pressure at which blue-violet field passes into opaque, at given temperatures of the inflowing air; or, more simply, by noting the mean pressures at which the blues change to yellows in the neighborhood of 30°.

The diversity of results obtained in this way for different nozzles is startling. The following data are selected at random from my notebook, θ being the air temperature at influx, and p the mean pressure corresponding to the blue opaque field.

TABLE 7.—Showing the effect of rough nozzles.

Number.	θ .	p .	Remarks. Diameter of bore, 0.09 cm.
	$^{\circ}$	Cm.	
I.....	30	41	Newly drilled and smoothed.
II.....	32	42	Do.
III.....	32	36	Do.
IV.....	32	38.5	III polished with steel tool.
V.....	31	34.5	Newly drilled.
VI.....	28	33	Brass plate, 3 mm. thick, newly drilled.
VII.....	29	41.5	Same; hole polished at both ends with emery.
VIII.....	30	46	Brass plate, 1 mm. thick; hole polished on both sides with emery.
IX.....	30	31.5	Platinum plate, two holes newly drilled; plate 2.5 mm. thick.
X.....	30	29	Same; holes reamed out with a needle.
XI.....	32	40	Same; hole polished at both ends with emery.
XII.....	30	45	Same; further polishing.
XIII.....	30	30	Another platinum plate, newly drilled.
XIV.....	30	37.5	Same; polished with emery.
XV.....	30	46	Same; further polishing.

Similar results (pressures ranging from 30 cm. to 44 cm.) were obtained with a larger bore 0.15 cm. in diameter. Thus there is no certainty that the size of the hole has an influence, since in any case an apparently insignificant roughness in the bore may change the condensation pressure (blue yellow) from 30 cm. to almost 50 cm. at 30° C. This is one of the grave difficulties of the koniscopic method proposed, for it is obvious that if the roughness of bore increases by corrosion or otherwise in the lapse of time the effect would be interpreted as an increase of dust contents. The nozzle should therefore be made of platinum. Glass nozzles are liable to break and difficult to fasten in place, and they are otherwise not superior to metallic nozzles.

The most effectual method of polishing the holes after drilling and smoothing consists in passing a piece of cotton twine saturated with oil and emery flour through the hole, and then wearing the latter down gradually, especially near the edges. All my endeavors to use steel reamers for the same purpose failed.

46. Sensitiveness.—When a nozzle has been made very smooth so that the condensation pressure (blue yellow at 30° C.) is above 45 cm. of mercury, it does not follow that the apparatus so obtained is sensitive to an equally marked degree. Indeed, the reverse seems to be the more usual case. Thus in the neighborhood of $p = 45$ cm. the transition from blue to yellow takes place within a pressure of 2 or 3 cm. of mercury, whereas below $p = 40$ cm. the transition is often complete within 1 cm. The most sensitive jets were always obtained without polishing. Thus a single hole 0.09 cm. diameter gave a blue field at 41.5 cm. and a yellow field at 42.5 cm. when the influx was at 32° . At the same medium temperature, two similar holes, about 0.4 mm. apart, showed a blue field at 39 cm. and a yellow field at 40 cm.; but I have not hit upon any sure method of producing these results in all cases. If the hole is too fine in bore, the colors are apt to be too faint. If the hole is too large, the opaque field is too intense and the colors too muddy. I should say that the duplex nozzle just described gave the best results.

The position of the nozzle in the color tube is also an item of importance. It should lie slightly below the axis of the influx pipe, but not above or below its upper or lower tangential planes. So far as possible the nozzle should squirt axially upward into the color tube.

There are a number of subsidiary results which may be added here, inasmuch as they throw light on the phenomenon in question. By allowing jets to play into color tubes of different widths, no change of the condensation pressure was observed, other conditions remaining the same. Thus the nozzle 0.09 cm. in diameter showed $p = 41$ cm. for $\theta = 30^\circ$ in a tube 5 cm. in diameter, and the same values of p and θ for a tube 8 cm. in diameter, the influx pipe for air being the same in the two cases. A like result was obtained for jets 1.5 cm. in diameter.

Similarly, in case of a brisk flow of steam, the length of the pipe conveying the steam to the jet has no effect, nor is an evident advantage gained by jacketing this pipe. Pipes as long as 100 cm. and more were tested.

Finally, the temperature of the color tube is without influence. If a fine sheet of cold water is allowed to run down the outside of this tube, the only obvious effect is a greater faintness of color due, to condensation. The condensation pressure and temperature do not perceptibly change (æst. par.). Thus in case of a drenched tube $p = 41$ at 28° , and in case of the same tube not cooled $p = 41$ at 29° —i. e., there is no evidence that the effect of cooling the color tube is anything beyond an additional condensation of steam.

There is sometimes an observable fall of the pressure p with the time during which the jet has been in action.

Premature condensation may often be counteracted, wholly or partially, by increasing the current of air.

47. Conclusion.—It follows from the remarks made in section 46 that each jet has a certain hydraulic individuality, which does not change so long as the nozzle is not changed either by corrosion or otherwise. At the same time the contours of the margin of the opaque field are alike in kind for all nozzles. Increments either of the dust contents of the air or of the roughness of the bore have a similar and mutually replaceable tendency to change the steady motion of the jet into eddying motion and thus to usher in the opaque field, followed by yellows of the first order.

I conclude from tables 5 and 6, interpreted in the light of the present and preceding results (sections 38, 39), that the excessively fine dusty constituent of the air—i. e., those particles which give rise to colored cloudy condensation, and are therefore virtually visible by interference methods—is a fixed attribute of normal atmospheric air and is invariable as to quantity.

[This unexpected and yet necessary conclusion of the experiments of the present chapter may possibly be interpreted in relation to Bidwell's discovery (section 11), viz, that actively dusty air largely loses its precipitating power on keeping in a closed vessel.—Feb. 2, 1895.]

CHAPTER IV.

THE THERMAL TOPOGRAPHY OF THE FREE STEAM JET.

PURPOSES OF THE WORK.

48. *Nature of the problem.*—If the steam jet is to be used as an instrument of research, and in the manner which the foregoing chapters have pointed out, then it is necessary to have a minute knowledge of the distribution of temperature throughout its length and breadth. The law expressing this distribution is therefore first to be investigated for any given conditions. It is then necessary to find how this law changes, both with the temperature of the medium of air into which the jet is discharged and with the pressure actuating the flow of steam. Finally, the effect produced when the jet is surrounded by a suitably ventilated tube is to be shown, and the distribution in this case compared with the results for the free jet. It appears from the above pages that when the color tube is used condensation is promoted or retarded by the temperature of the inflowing air in a well-marked manner, and it is thus through the color tube that the nature of the medium-constant is most clearly apprehended.

49. *Pressure and volume.*—In addition to temperature, the distribution of pressure and volume throughout the steam jet are important desiderata, for these are the variables which must be known if the isothermals are to be traced experimentally. The instrument for the measurement of pressure at any point is not yet forthcoming; much less is it possible to determine the volume which obtains for the given point. All such experiments are made doubly difficult by the rush of the condensing steam from an orifice. There is, therefore, an essential incompleteness in the measurements made upon steam jets, and a part of the conclusions reached must remain inferential.

On the other hand, condensation as seen in the steam jet is virtually steady and so clear cut in its nature that whatever information can be obtained of the details of the phenomenon can not but be important. It is for this reason that I have gone extensively into the question of temperature distribution, as shown in the following paragraphs.

50. *Literature.*—I have found nothing in the literature of the subject sufficiently precise in its nature to be available for the present purposes.

APPARATUS.

51. Jet.—The nozzle of the jet in these experiments was similar to those above used, except that special means were provided for attaching and moving the thermocouple. In fig. 24 one end of the tube *a b* communicates with the steam box (which in the present work was made wholly of gas pipe, being stronger and of smaller capacity than the one shown in fig. 6). The other end of *a b* carries the short tube *c*, with a hole at *n*, from which the jet is to issue. The cap *d d* closing the outer end of *c* makes with it an ordinary stuffing box, by which the insulator *f* of one junction of the thermocouple is secured in place. Thus the temperature of the steam may be measured at *e*, immediately before leaving the nozzle *n*.

The other and movable end of the thermocouple is adjusted by means of a suitable clamp, *k*, free to slide up and down the standard *g*. In this

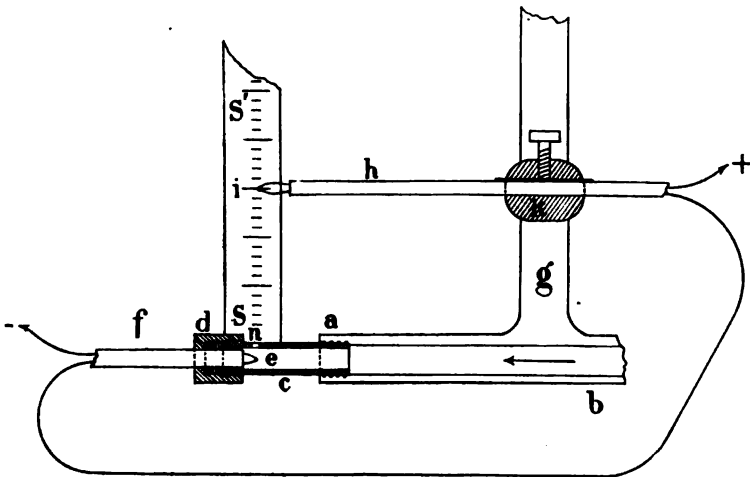


FIG. 24.—Free steam jet with attachments, etc.

way the insulator *h* of the couple may be so placed that the junction *i* takes any desirable position above the nozzle *n*, and the height of *i* above *n* is read off on a scale, *S S¹*, etched on mirror glass, placed vertically behind the jet. By keeping the images of the eye and of the junction in coincidence, increments of height may thus be read off as closely as necessary. It is not so easy to fix the junction in the axis of the jet.

The slide *g* is rigidly attached to the tube *a b*. When temperatures are to be taken across the jet, *g* is replaced by a horizontal slide corresponding to a horizontal scale, *S S¹*.

When the junction *e* is not used, the cap *d d* is replaced by a tube and stopcock bent vertically downward; for by keeping this cock slightly open the water condensing in *a b* is discharged, and the annoyance of drops choking the nozzle *n* is obviated. Possible changes of temperature produced by the additional aperture are not to be overlooked.

¹ Cf. Bulletin U. S. Geological Survey, No. 54, p. 95 et. seq., 1889.

All parts of the steam box and the conveyance tubes are to be properly jacketed with blanketing, so as to diminish loss of heat by radiation.

52. Temperature measurement. Thermocouple.—The thermocouple is the only apparatus available for the present work. I made use of thin wires of German silver and of copper, soldered together at as fine a point as possible. The wires were kept apart by insulators of fire clay,¹ leaving only the junction exposed, as shown in fig. 24. Where measurements (as in the present instance) are to be made by the galvanometer, the resistance of the couple is a consideration. Hence I constructed half couples, as they may be called, containing a single junction between a meter length of copper wire and a half-meter length of German-silver wire. The free ends of the copper wires were always to be used as the terminals of the couple, and therefore led to the galvanometer. The free ends of the German-silver wires were soldered together when any two points were to be thermally compared. Thus, by putting a junction in the steam box, another below the steam nozzle (as shown in fig. 24), a third in the jet (also shown in fig. 24), and a fourth in a normal boiling point apparatus, I had the means of finding the difference of temperature between any two of these points.

53. Temperature measurement. Galvanometer.—To measure the thermocurrent produced, I made use of my torsion galvanometer.¹ In this instrument the needle is kept in a fixed plane parallel to the winding and all current expressed directly in terms of the torsion of a platinum fiber. If D be the amount of twist observed when the temperature of the junctions of the thermocouple are respectively T and t , then

$$D = a(T-t) + b(T^2 - t^2) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

a well-known equation, in which a and b are constants. Remembering that the resistance of the circuit is constant, and is largely (almost wholly) in the coils of the galvanometer, a calibration is to be made once for all, by finding the values of D when the temperatures of the junctions are known. In this way a and b were computed and found to be (at a temperature of the galvanometer of 10°)

$$a = 0.8967; \quad b = 0.001167; \quad c = \frac{b}{a} = 0.0013.$$

These constants necessarily vary, and vary in marked degree when the temperature of the coils changes, for a greater resistance is now introduced and the elastic and magnetic constants are no longer the same. But the effect of this is to alter the constants a and b individually; it can not alter the relation $\frac{b}{a}$, since this depends only on the couple. Hence, if equation (1) be expressed

$$D = a(T-t)(1 + c(T+t)) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

¹Barus: Bulletin U. S. Geological Survey, No. 103. Cf. "Behandlung u. Messung hoher Temperaturen," p. 82; Barth, Leipzig, 1892.

where c is known, only a single measurement suffices to determine the new value of a . Thus the recalibration is simple, for it is merely necessary to put the hot junction in steam and the other in cold water of known temperature to find the appropriate a for the day.

In this way during the course of some three months I found temperature 10° , $a = 0.897$; 16° , $a = 0.880$; 20° , $a = 0.867$, showing the temperature coefficient to be about -0.003 per degree Centigrade. For ordinary accuracy, therefore, recalibration is also superfluous, since the coefficient is known.

Finally, to measure temperature by the aid of (2) one of the values T or t must be known, and the other is therefore given by the equation. The work is facilitated by writing this equation

$$D + at + bt^2 = aT + bT^2,$$

or

$$D + f(t) = f(T),$$

and computing a table for the function $f(t) = at + bt^2$.

RESULTS.

54. Notation.—The results obtained are given in the following tables (8 to 10) in a way showing how the method was gradually perfected. Two commutations at the torsion galvanometer were made for each temperature measurement. Consequently each datum for temperature is the mean of three observations, corresponding to three readings for the actuating steam pressure (P) also averaged.

This premised, P denotes the pressure of the steam in the steam box directly observed in centimeters of mercury. P is therefore properly the excess of the steam pressure above the atmospheric pressure. T^1 denotes the corresponding boiling point of water taken from well-known tables¹. T is the temperature just well inside of the nozzle of the jet, computed from observations given in section 61. Finally, t is the temperature sought—i. e., the temperature at an axial point of the steam jet H cm. above the nozzle for the given temperature, θ , of the medium of air into which the steam discharges, and the actuating steam pressure (steam box) P .

As a rule the difference of temperature between the steam box and the divers points of the jet was directly measured thermoelectrically. In this case, if the Avenarius-Tait equation of the thermocouple be put

$$f(T) - D = f(t), \quad \dots \dots \dots (1)$$

where D is the observed twist and the functionality $f(T) = aT + bT^2$; and where a and b are the constants measured and corrected as shown in section 53—then since D is directly observed (torsion galvanometer) and T is known through P , the quantity $f(t)$ is also known, and therefore t is easily derived. Thus, it is merely necessary to construct a

¹Cf. Landolt u. Boernstein: Phys.-chem. Tabellen, pp. 40-46, Berlin, 1883.

table for the function $f(T) = aT + bT^2$ between about 0° and 150° , graphically, and to construct a similar table for the vapor tension of water between those limits, to have in hand the apparatus for the easy computation of the temperature t at any specified point of the steam jet.

With the object of introducing desirable variations of method, I occasionally measured the difference of temperature (galvanometer twist D) between the inside of the nozzle and the points of the jet. In such a case T in equation (1) must be replaced by T^1 already defined.

Again, I measured the difference of temperature between the steam of a normal boiling point apparatus and the points of the jet. Here G is to be replaced by T'' , the boiling point of water for the barometric height of the day.

55. Earlier data.—After the explanations given in the preceding paragraph, the data of Table 8 will be easily understood. The chart, fig. 25, belongs to this table. The table consists of four parts, A to D , containing different sets of observations, with a final summary of the chief results.

The first set under A is disappointing, for the variations (not on the chart) are cyclic. To find out whether this was really the case, I placed one of the junctions of the thermocouple in a boiling point apparatus, obtaining the data of the next set under A . The results so obtained are clear enough. They indicate a linear variation of the temperature at a given height ($H=0.4$ cm.) above the nozzle, with pressure P , the slope being 0.093 and the initial temperature ($P=0$), 94.6° .

The final set of data under A are corroborative. They show that the observed (thermoelectric) and the computed (from P) temperature of the steam box differ by 0.8° C., which, however, is nothing more than the temperature correction of the torsion galvanometer. Section 53.

TABLE 8.—Change of temperature at a given axial point with the actuating steam pressure. Earlier results. Nozzle one-sixteenth inch in diameter.

A. $H=0.4$ cm.¹

P	T^1	T	t	$100-t$	$T-t$	$\frac{dt}{dp}$ °C.
<i>Cm. Hg.</i>	°C.	°C.	°C.	°C.	°C.	(1)
10.0	103.4	102.6	90.5	9.5	12.1	.....
31.0	109.7	108.8	91.2	8.8	17.6	.....
74.3	120.3	119.1	86.1	13.9	23.0	.....
53.9	115.6	114.6	85.6	14.4	29.0	.....
36.8	111.4	110.5	87.2	12.8	23.3	.....
26.2	109.1	108.2	88.2	11.8	20.0	.....
16.9	105.6	104.8	88.2	11.8	15.6	.....
10.1	103.5	102.7	90.0	10.0	12.7	.....

$H=0.4$ cm. $T''=100^\circ$ C.²

22.0	107.4	106.6	96.7	-3.25	109.8	+0.093
39.6	112.3	111.4	98.2	-1.80	113.2	94.6°
52.5	115.4	114.4	99.3	-.70	115.1	.....
82.8	122.0	120.8	102.6	+2.63	118.2	.....

¹ Junctions in steam box and in jet.

² Cyclic change negative.

³ Junctions in boiling-point apparatus and in jet.

TABLE 8.—Change of temperature at a given axial point, etc.—Continued.

Steam box and boiling-point apparatus. $T' = 100^{\circ} \text{C.}^1$

P	T^1	T	t	$1.0-t$	$T-t$	$\frac{dt}{dp} t_0$
<i>cm. Hg.</i>	<i>°C.</i>	<i>°C.</i>	<i>°C.</i>	<i>°C.</i>	<i>°C.</i>	(<i>l</i>)
14.3	104.7	103.9	105.5	.....	— 0.8	.....
29.2	109.3	108.4	110.1	.....	— 0.8	.....
49.2	114.5	113.5	115.3	.....	— 0.8	.....
66.7	118.4	117.3	119.1	.....	— 0.7	.....

B. $H = 1.5 \text{ cm.}^2$

10.8	103.6	102.8	74.9	.....	27.9	(0.071)
22.5	107.4	106.6	74.3	.....	32.3	72.6°
35.3	111.0	110.1	74.3	.....	35.8	.....
48.8	114.4	113.4	76.1	.....	37.3	.....
62.5	117.6	116.5	77.4	.....	39.1	.....
76.8	120.7	119.5	80.1	.....	39.4	.....
73.3	120.0	118.9	79.5	.....	39.4	.....
59.3	116.8	115.7	77.4	.....	38.3	.....
45.9	113.6	112.6	75.6	.....	37.0	.....
30.1	109.5	108.6	73.9	.....	34.7	.....
16.8	105.7	104.9	73.8	.....	31.1	.....

 $H = 3.8 \text{ cm.}^2$

12.4	104.3	103.5	58.2	.....	45.3	(0.071)
27.7	108.8	107.9	57.5	.....	50.4	56.2°
44.1	113.4	102.4	60.0	.....	42.4	.....
53.0	115.5	114.5	60.4	.....	51.1	.....
61.3	117.4	116.3	61.7	.....	51.6	.....
40.9	112.5	111.5	59.5	.....	52.0	.....
23.7	107.8	107.0	57.5	.....	49.5	.....
11.7	104.0	103.2	56.5	.....	46.7	.....

 $H = 8 \text{ cm.}^2$

9.3	103.2	102.4	44.4	.....	58.0	0.071
22.3	107.4	106.6	45.5	.....	61.1	44.1°
43.8	113.3	102.3	47.0	.....	55.3	.....
68.2	118.9	107.8	49.4	.....	58.4	.....
51.0	115.0	104.0	47.6	.....	56.4	.....
29.6	109.5	106.6	46.5	.....	62.1	.....
13.5	104.6	103.8	45.4	.....	58.4	.....

C. $H = 0.8 \text{ cm.}$ Medium $\theta = 30^{\circ} \text{C.}^3$

9.0	103.2	102.4	80.4	.....	32.0	(0.071)
20.8	106.8	106.0	80.5	.....	25.5	(79.5°)
34.6	110.7	109.8	82.0	.....	27.8	.....

 $H = 0.9 \text{ cm.}$ Medium $\theta = 27^{\circ} \text{C.}^3$

9.8	103.4	102.6	80.6	.....	22.0	(Negative).
23.3	107.6	106.8	77.0	.....	29.8	.....
52.0	115.3	114.3	70.6	.....	43.7	.....

D. SUMMARY.

$P = 0$	$H = 0.4 \text{ cm.}$	$t_0 = 94.6^{\circ} \text{C}$	$\frac{dt}{dp} = 0.093$
$P = 0$	$= 0.8$	$= 79.5$	⁴ (0.071)
$P = 0$	$= 1.5$	$= 72.6$	(0.071)
$P = 0$	$= 3.8$	$= 56.2$	(0.071)
$P = 0$	$= 8$	$= 44.1$	0.071

¹ Junctions in boiling-point apparatus and in steam box.² Junctions in steam box and in jet.³ Junction in steam box and in jet. Jet tube loosening?⁴ Data in parentheses are approximate, and inferred from the last value.

The data under *B*, for heights respectively $H=1.5, 3.8, 8.0$ cm. above the nozzle, are more outspoken. The noncyclic linear character of the curves and the positive slopes are sustained more or less throughout, but particularly at $H=8$ cm., when the jet is broader and the axial observations more certain. Initial temperatures and slopes are summarized under *D*.

C contains a few supplementary results for positions H , near the nozzle. The temperature θ of the medium is given. It is absent in the earlier work. The second set under *C* is again negative, like the first under *A*, showing the great difficulty in obtaining the temperatures very near the nozzle, where the jet is narrow. Section 60.

In the summary *D* the initial temperature t_0 at $P=0$, in its depend-

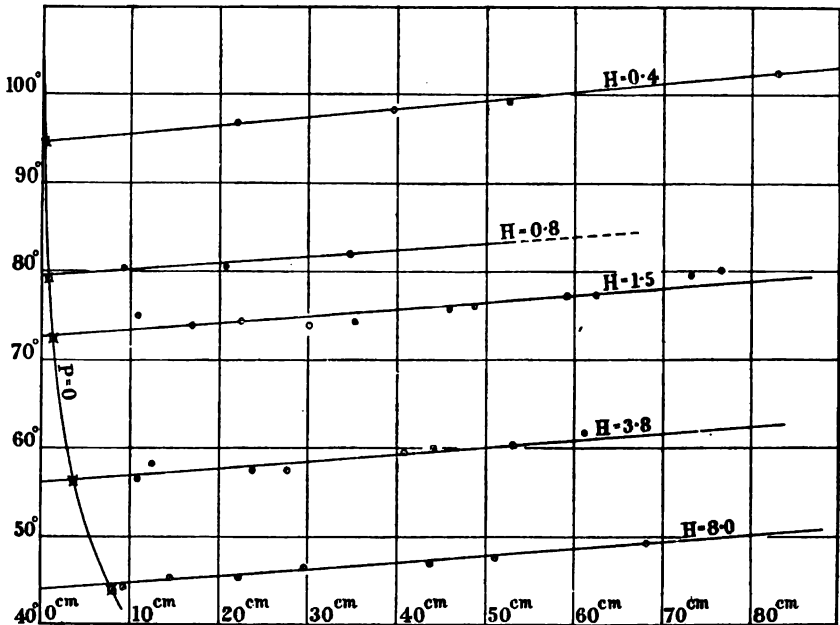


FIG. 25.—Chart showing the increase of temperature for different pressures actuating the steam jet.

ence on the height above the nozzle is the interesting datum and is given graphically in the chart, fig. 25. Contrary to my expectations (for the temperature of the medium, etc., was not always taken), these values (t_0) form a curve of well-marked contour. I will discuss it below sections 59, 69, and here merely remark that at any height above the nozzle the character of the variations of the jet temperature (t) with the actuating pressure (P) is such that when P approaches zero t reaches a definite limit greater than zero, and definitely decreasing with H .

56. Errors.—After these encouraging results I resolved to perfect the method, taking into account the chief causes of the discrepancies encountered. The occurrence of supersaturation in the steam box may be dismissed, for the steam tarries here for some time and the observations under *A*, Table 8, are proof against it. Similarly, progressive

leaks in the pipes (a probability in case of the second set under *C*) are soon discovered. Drops are apt to condense on the thermoelectric junction and distort the results. The junction should be inclined so that drops may run off.

There remain three other chief sources of error—viz, the irregularity of the air temperature in a heated room in winter, its ulterior disturbing effect on the torsion galvanometer, and the difficulty in placing the junction axially in the jet. As for the room temperature, if the jet is to discharge freely into the air, the difficulty is well-nigh insuperable in winter, for cold-room temperatures alone are not sufficient to bring out the whole phenomenon. A season of variable temperatures and a room not heated are the desiderata, but which were not forthcoming during the course of my work. Perhaps a very wide vertical funnel shaped tube, with a narrower tubular opening in the bottom containing a thermometer to register the temperature of the inflowing air, and the jet axially fixed and playing vertically upward above the hole, might practically leave the surface conditions unchanged, but I have not tried it.

Aside from this, the chief error in the results of Table 8 is the insufficiently perfect axial adjustment of the thermocouple. This is proved by the fact that the curves tend to become smoother when the measuring junction is moved from points near the nozzle to the wider parts above. Where the jet issues its width is not much above one-sixteenth of an inch, and within this fine filament the radial distribution of temperature falls off from (say) 100° to (say) 20° . The upper parts of the jet may be 5 or even 10 cm. in maximum width. (Cf. section 58.) Again, an obstruction like the junction tends to deflect the jet unless everything is quite symmetrical. Hence, it is only natural that, with increasing pressure, the assymetry should also vary. In this way the negative slopes of observations near the nozzle are sufficiently accounted for, as will be more fully shown in section 60. Temperatures near the nozzle are apt to be measured too low.

If the junction be too near the nozzle, the flow of steam is possibly diminished; but I do not think this difficulty has entered my work. The construction of the steam box is such that pressures must be the same at the tube of the manometer and at the junction of the thermocouple in the box. Instead of the pressures in the steam box, the computed pressures in the nozzle might have been given; but the former, being data of observation, are preferable.

57. Further data. High temperature environment.—Hence in my remaining experiments the slide supporting the thermoelectric junction was rigidly attached to the nozzle, and great precautions were taken to secure an axial adjustment. As a result, negative slopes have not again been encountered and the curves show greater smoothness and consistency throughout.

In Table 9 the medium is at the relatively high temperature $\theta = 26^{\circ}$

to 27°. Under these circumstances the visible part of the steam jet was about 50 cm. long and 5 cm. in diameter. As Table 9 shows (data for P), the work was usually done cyclically, but the curves are not cyclic.

In the part A of the table the hot junction was in the steam box and its temperature therefore T^1 , from which t is computed. In the part B the hot junction was placed in the jet tube just below the nozzle.

The chart Pl. I accompanies this table, and observations A are indicated by circles, observations B by crosses.

TABLE 9.—*Change of temperature at a given axial point of the jet, with the actuating steam pressure. Barometer 76 cm.*

$A. H=0.9$ cm. Medium 27° C.¹

P	T^1	T	t	$T-t$	$\frac{dt}{dp} t_c$
11.5	104.0	103.2	77.6	25.6	0.060
25.9	108.4	107.5	77.2	30.3	76.6°
44.6	113.4	112.4	77.8	34.6	.....
67.6	118.7	117.6	81.0	36.6	.....
54.3	115.7	114.7	78.6	36.1	.....
34.7	110.7	109.8	79.4	30.4	.....
9.5	103.3	102.5	77.5	25.0	.....

$H=2.5$ cm. Medium 27° C.¹

9.7	103.4	102.6	63.4	39.2	.....
28.3	109.2	108.3	64.3	44.0	0.090
48.7	114.5	113.5	67.0	36.5	62.3°
38.8	111.9	111.0	65.6	45.4	.....
24.7	108.2	107.3	64.2	43.1	.....
12.8	104.4	103.6	63.6	40.0	.....

$H=15$ cm. Medium 27° C.¹

9.8	103.4	102.6	34.3	68.3	.....
25.3	108.3	107.4	35.3	72.1	0.044
46.8	114.0	113.0	36.3	76.7	34.0°
62.7	117.7	116.6	36.7	79.9	.....
52.6	115.4	114.4	36.2	78.2	.....
34.0	110.6	109.7	35.5	74.2	.....
15.8	105.4	104.6	35.4	69.2	.....

$H=31$ cm. Medium 27.5° C.¹

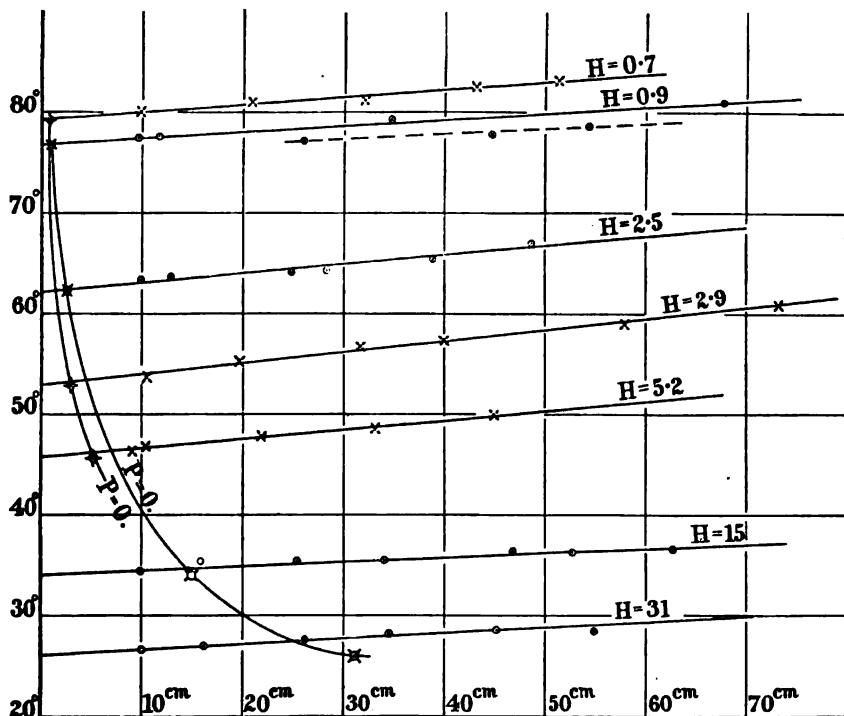
16.2	105.5	104.7	27.0	77.7	0.056
26.1	108.5	107.6	27.7	79.9	26.0°
45.2	113.6	112.6	28.5	84.1	.....
54.9	115.9	114.9	28.5	86.4	.....
34.5	110.7	109.8	28.1	81.7	.....
10.0	103.4	102.6	26.7	75.9	.....

$B. H=0.7$ cm. Medium 25° C.²

9.7	103.4	102.6	80.1	22.5	0.070
32.0	110.2	109.3	81.3	28.0	79.4°
51.2	115.1	114.1	83.2	30.9	.....
43.0	113.1	112.1	82.7	29.4	.....
20.8	106.8	106.0	81.1	24.9	.....

¹ Hot junction in steam box.

² Hot junction just below nozzle.



Curves H showing the increase of temperature (ordinates) for the different pressures (abscissas in cm. of Hg) actuating the steam jet at different heights (H in cm.) above the nozzle.
 Curves P showing the limiting value ($P=0$) of the temperature (ordinates), at different heights above the nozzle (abscissas in cm.) when the actuating pressure approaches zero.

TABLE 9.—*Change of temperature at a given axial point of the jet, with the actuating steam pressure. Barometer 76 cm.—Continued.**H=2.9 cm. Medium 26° C.¹*

<i>P</i>	<i>T</i>	<i>T</i>	<i>t</i>	<i>T-t</i>	$\frac{dt}{dp}, t_0$
10.5	103.6	102.8	53.7	69.1	0.110
31.7	110.0	109.1	56.8	52.3	52.9°
73.3	120.0	118.8	60.9	57.9	.....
58.0	116.6	115.5	59.1	56.4	.....
40.4	112.4	111.5	57.5	54.0	.....
19.6	106.5	105.7	65.4	40.3	.....

H=5.2 cm. Medium 27° C.¹

9.0	103.1	102.3	46.4	55.9	0.093
33.2	110.4	109.5	48.6	60.9	45.7°
44.9	113.5	102.5	50.0	52.5	.....
21.6	107.2	106.4	47.9	58.5	.....
10.3	103.5	102.7	46.9	55.8	.....
52.2	115.4	114.4	49.6	64.8	.....

¹ Hot junction just below nozzle.C. SUMMARY: *P=0*.

<i>H=0.9 cm.</i>	<i>t₀=76.8°</i>	$\frac{dt}{dp}=0.090$	<i>H=0.7 cm.</i>	<i>t₀=79.4°</i>	$\frac{dt}{dp}=0.070$
=2.5	=62.3°	.090	=2.9	52.9°	.110
=.15	=34.0°	.044	=5.2	45.7°	.093
=.31	=26.0°	.056			

Taking these results as a whole (Pl. I), the linear relation of the temperature at any given point of the jet and the actuating steam pressure can no longer be doubted. The groups *A* and *B* are distinct. This is best seen in the summary *C*, Table 9. If the limiting temperature (*t₀* for *P=0*) at divers heights in the jet be constructed, the two loci "*P=0*" of the chart are obtained. They are alike in character (section 59). Their difference is such as to imply a colder medium in the case *B*, probably much colder than the data actually observed. (Section 60, end.)

Moreover, the slopes of the lines *A* are as a rule smaller than those of *B*; but here, as in the case of the variation of the slope with the position *H* of the point, the evidence is not certain. The distortion is largely due to the fact that an axial position of the junction was not uniformly obtained, and for this reason the changes of slope are irregular. A mean value for each set *A* and *B* will best represent the conditions, aside from *H*.

58. Data. Low-temperature environment.—Table 10 contains results for a steam jet discharging into cold air. At 15° C. the appearance as compared with the foregoing is quite striking, for the jet has now fully doubled its former dimensions,¹ being about a meter long and 10 cm. in diameter. This indicates the importance of a more accurately defined

¹ Barus: Am. Meteo. Jour., x, p. 11, 1893.

and constant air temperature than the present paper evidences, and is in keeping with my earlier results¹ on the contours of the opaque field in Chapter III. Because of these swollen dimensions of the jet, the axial adjustment of the thermocouple is more easily made (probably); at least the present observations are the smoothest of the whole series. A few alterations were made at the manometer, a wider tube and a glass scale being inserted.

The two parts *A* and *B* of the table differ, as explained in the foot notes, and the summary, *C*, contains the derived results.

TABLE 10.—*Change of temperature at a given axial point with the actuating steam pressure. Barometer 76 cm.*

A. H=1.1 cm. Medium 20°; Galv. 12° C. a

<i>P.</i>	<i>T</i> ¹	<i>T.</i>	<i>t.</i>	100— <i>t.</i>	<i>T—t.</i>	$\frac{dt}{dp} t_0$
<i>Om. Hg.</i>	°C.	°C.				
9.2	103.2	102.4	71.6	.....	30.8	0.120
34.6	110.7	109.8	74.3	.....	35.5	70.4°
49.1	114.5	113.5	76.3	.....	37.2	
56.2	116.2	115.1	77.4	.....	37.7	

B. H=0.4 cm. Medium 17.5° C. T¹ 100.2° (constant). b

13.1	104.5	103.7	82.9	.....	20.8	0.124
28.9	108.6	107.7	84.6	.....	23.1	81.3°
42.0	112.7	111.7	86.9	.....	24.8	

H=0.8 cm. Medium 17.0° C. b

15.7	105.4	104.6	80.8	.....	23.8	0.127
31.5	110.0	109.1	82.7	.....	26.4	78.7°
41.8	112.7	111.7	84.1	.....	27.6	

H=2.5 cm. Medium 17.6° C. b

11.6	104.0	103.2	60.1	.....	43.1	0.120
33.0	110.4	109.5	62.7	.....	46.8	58.6°
44.3	113.4	112.4	64.0	.....	48.4	

H=4.6 cm. Medium 18.0° C. b

8.2	102.8	102.0	46.2	.....	55.8	0.204
26.7	108.6	107.7	50.0	.....	57.7	44.4°
39.4	112.2	111.3	52.5	.....	58.8	

a Hot junction in steam box.

b Hot junction in boiling-point apparatus.

C. Summary, P=0. Medium 17°–18.0°.

<i>H=0.4 cm.</i>	<i>t₀=81.3°</i>	$\frac{dt}{dp} = 0.124$
0.8	78.7	.127
(1.1)	(70.4)	(.120)
2.5	58.6	.120
4.6	44.4	.204

¹ Aitken's observations on the effect of cold on jets are given in Proc. Roy. Soc., LI, p. 414, 1892.

The chart Pl. II accompanies this table, the height H of the point of observation being, as usual, marked on the lines. The data of the summary ($P=0$) are inscribed on the right side of the chart, and they are consistent throughout, showing a curve of the kind already met within the earlier results, but with a clear tendency to become tangent to a lower asymptote.

The marked feature of these results is the large values of the slopes, thus bearing out the inferences made in case of the preceding tables, where the slope was found to increase when the temperature of the medium decreased. (Section 57.)

59. Longitudinal distribution of temperature.—Having obtained a satisfactory expression for the variation of temperature at any axial point of the steam jet when the actuating pressure varies, the next results to be sought for are the distributions along the axis from point to point, as well as the radial distribution within any right section. Some notion of the former of these cases has already been obtained from the data of Table 8 to 10 or Plates I and II; for by selecting all the values of the jet temperature which correspond to a given pressure (for instance, $P=0$), the dependence of the stated temperature of the height H of the point above the nozzle appears. This method is not apt to give the best results, however, owing to the fact that the temperature of the medium and other secondary conditions are apt to vary during the long intervals of observation.

I have therefore made special observations on the longitudinal distribution of temperature by using the jet with attached slide shown in fig. 24, and the results are given in Table 11, where H denotes the height above the nozzle at which the temperature is t at the constant pressure P .

The best results obtained are those under A , where the pressure is maintained at $P=50$ cm. A full set of measurements was also made for $P=25$, nearly; but unfortunately the medium of air was colder. A fragmentary series was made for $P=75$ cm., as the available steam did not enable me to complete the work. The medium here was at a higher temperature (datum lost) than in either of the other series.

The data of Table 11 are inscribed in the chart, Pl. I (curves P), and the probable nature of the contours is shown clearly enough. Owing to the difference of air temperature, however, the curves are not at once comparable. Accepting the vertical distributions given by any one of them, the changes due to pressures are found from Tables 8 to 10, above, as will presently be shown (sections 64, 65).

TABLE 11.—*Axial distribution of temperature in the steam jet.*A. Galv., 12°; medium, 17.5°-18.0°; barometer, 76 cm. $P = 50$ cm.¹

<i>H.</i>	<i>T.</i> ¹	<i>T.</i>	<i>t.</i>	<i>T-t.</i>
<i>Cm.</i>	°C.	°C.	°C.	°C.
0.5	114.7	113.7	83.1	30.6
1.1	114.7	113.7	76.4	37.3
1.3	114.6	113.6	72.6	41.0
3.2	114.7	113.7	57.0	56.7
5.3	114.8	113.8	48.5	65.3
8.1	114.7	113.7	40.7	73.0
12.0	114.7	113.7	34.2	79.5
17.1	114.8	113.7	28.9	84.8
23.9	114.9	113.8	24.6	89.2
35.0	114.8	113.7	20.5	93.2

B. Medium, 16°-18°. $P = 24.5$ cm.²

0.9	108.1	107.2	77.2	30.0
2.0	108.2	107.3	65.4	41.9
3.4	108.1	107.2	57.5	49.7
3.9	108.1	107.2	51.6	55.6
5.2	108.0	107.1	46.6	60.5
7.0	108.0	107.1	40.6	66.5
11.8	108.2	107.3	32.5	74.8
15.0	108.1	107.2	28.7	78.5
20.5	108.2	107.3	24.1	83.2
27.5	108.2	107.3	20.5	86.8

C. Medium? $P = 75$ cm.¹

1.2	120.6	119.4	78.3	41.1
3.3	120.5	119.3	64.0	55.3
5.8	120.5	119.3	53.6	65.7
9.6	*119.6	118.5	44.7	73.8

¹ Hot junction in steam box.² Hot junction in the nozzle.³ Steam low.

60. *Radial distribution.*—The expansion of the visible envelope of the jet when the temperature of the medium is decreased has already been alluded to. (Section 58.) Inasmuch as the bulk or unclear part of the jet is a region of condensation, and the mantel or margin a region of evaporation (for the water globules here disappear by solution and evaporation), the radial distribution of temperature is of considerable interest. One might reasonably expect the outer surface of the jet (not too near the nozzle) to be at a temperature below that of the atmosphere.

I have commenced a study of this subject since it does not enter directly into the present work, and a few data are given in Table 12. Pressure P being maintained at 25 cm. of mercury, observations were made about 12 cm. above the nozzle, where the apparent width of the column of steam was about $2R = 4$ cm. The radial position of the thermoelectric junction is given in centimeters under r , so that the first position ($r = 0$) was in the axis, the third in the outer surface of the jet, and the last ($r = 4$) in the circumambient air.

TABLE 12.—*Radial distribution of temperature in the steam jet* $H = 12$ cm.; $P = 25.0$ cm., Hg.; $2R = 2 \times 2$ cm.; medium 18° C.¹

r .	T .	T' .	t .	Remarks.
Cm.				
0	108.2°	107.3°	32.5	Center.
1			26.9	Middle.
2			16.4	Edge.
4			13.1	Air.

¹ Hot junction just below nozzle.

These results are also given on Pl. II, in the curve ca , of which the ordinates are temperatures and the abscissas distances in centimeters (r) of the point in question from the axis of the jet, or from the center of the right section, 12 cm. above the nozzle. Since the medium was at a temperature of nominally 18° , the low temperatures (16.4° , 13.1°) occurring near the edge of the jet are striking features.

Owing to the apparently anomalous way in which the air temperature enters the foregoing results, I carefully repeated the work by surveying across the jet, keeping the junction on a horizontal line (high H above the nozzle) passing through the axis of the jet. In the next table, R is the position of the junction relative to this arbitrary horizontal scale, and t the corresponding temperature. P and T denote pressure and temperature in the steam box, as usual.

TABLE 13.—*Radial distribution of temperature in the steam jet.*

$H = 25$ cm. $P = 30$ cm. $T = 109.5^\circ$.					
R .	t .	R .	t .	R .	t .
Cm.	°C.	Cm.	°C.	Cm.	°C.
39.5	17.0	31.0	27.0	24.0	17.6
37.0	17.4	29.5	29.6	22.0	16.6
34.0	19.4	28.0	28.6		
32.5	22.5	26.0	23.3		
$H = 25$ cm. $P = 50$ cm. $T = 114.7^\circ$.					
40	18.3	30	28.3	22	17.3
37	18.6	28	30.6	20	17.2
34	19.4	26	26.5	40	17.3
32	24.0	24	19.5		
$H = 13$ cm. $P = 50$ cm. $T = 114.7^\circ$.					
37.5	18.7	27.5	34.0	32.0	19.5
34.5	19.0	26.0	20.4	30.0	32.9
32.5	19.5	24.0	17.3	28.5	37.8
31.0	28.6	22.0	17.3	27.0	29.6
30.5	29.1	38.0	17.9	25.0	17.7
29.0	37.7	34.0	18.3		

The results are graphically shown in the chart, fig. 26, where temperatures are the ordinates and points along a diameter the abscissas. The whole temperature variation occurs within the visible width of the jet. Moreover, the maxima are sharp, so that in a general way one can

put the temperature at any point along the horizontal radius as a mean between the air temperature and the corresponding temperature at the center of the right section (axis). None of the curves are quite symmetrical, but this is due to incidental causes, for the jet was not quite vertical and the conveyance pipes lay largely to the right or hotter part of the jet.

The chief point gained in this work is the fact brought out that the jet temperatures fall off radially into the air temperature, and that they do not pass through a minimum, as was supposable. Further and direct observations (which I will omit) showed the cause of relatively cold temperatures around the jet to be referable to an unequally heated room, for the air rushing up around the jet came largely from the floor and was sensibly colder than the mean room temperature.

61. Fall of temperature in the connecting pipe.—The tube connecting the nozzle with the steam box was made as short as the other needful

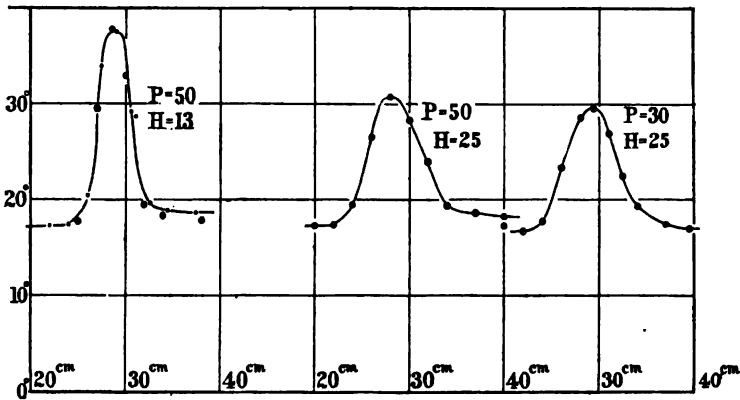


FIG. 26.—Radial distribution of temperature.

adjustments would permit. But a piece of rubber hose 40 cm. long (including the brass end pieces), securely wrapped with cloth and non-conducting felting, was essential. The result, nevertheless, is a difference of temperature between the steam box and the inner face of the nozzle, as shown in Table 14. Here one of the thermoelectric junctions was placed in the steam box as usual, and the other in the jet pipe just below the nozzle.

The fall of temperature is not negligible, but it is not seriously large. The interesting feature about it is, that the difference of temperature ($T-t$) is clearly a linear function of the actuating pressure,

$$(T-t) = 0.70^\circ + 0.0063 P,$$

as is shown by the curve *mn* of Pl. II. Thus, in a smaller scale, the inferences and observations of sections 57, 58 (curve *H*) are reproduced, even in the case of restricted expansion in pipes. The curve *mn* is such as to imply a definite difference of temperature (0.7°C.), even when the actuating pressure approaches zero, and this difference

increases with pressure at the rate 0.0063°C. per centimeter of mercury indefinitely.

TABLE 14.—*Distribution within the inflaz pipe. Jet 1 meter long, 10 cm. wide; medium 16° .*

[Junctions respectively in the nozzle and in the steam box.]

$P.$	$T.$	$t.$	$T-t.$	$\frac{d(T-t)}{dP}; (T-t)_{\infty}$
6.0	102.2	101.5	0.72	0.0063 0.70
22.5	107.4	106.5	.86	
37.6	111.6	110.7	.92	
46.2	113.8	112.8	1.01	

With these very definite results in hand it is easy to compute either the temperature or the pressure of the steam, just before leaving the nozzle, from the pressures observed in the steam box. In view of the low room temperature (16°) the present test is a severe case.

INFERENCES.

62. Structure of the jet—Before proceeding to a discussion of the above data it is in place to insert a few words on the appearance of the jet near the nozzle. This is found to be strikingly like the Bunsen flame, where a mantel of combustion surrounds a blue cone of unburnt gas. So in the steam jet the axis immediately above the nozzle is surrounded by a colorless spindle-shaped region, consisting largely of uncondensed vapor, which in its turn is enveloped by the opaque mantle of condensation. The latter does not reach downward quite to the plane of the nozzle, but terminates in a ring parallel to the nozzle and at a distance about it decreasing when the actuating steam pressure increases or the temperature of the medium decreases. Thus, at 18°C. , the following values of the heights (h) of the condensation limit were found at different steam pressures (p)

$$\begin{array}{cccccccc} h = 0.9 & 1.1 & 1.3 & 1.8 & 1.5 & 2.0 & 1.2 & 0.9 \text{ cm.} \\ p = 44 & 37 & 26 & 13 & 3 & 18 & 29 & 36 \text{ cm.,} \end{array}$$

showing some irregularities due to the difficulty of observing, but bearing out the statement made clearly enough. The condensation limit at 18° falls about 0.04 cm. per mercury cm. of increase of the actuating steam pressure.

Now, just as in the case of the Bunsen flame, the contours are a locus indicating the speed of the chemical reaction, so in the case of the steam jet the position of the ring in question indicates the speed of condensation. From this an important consequence may be drawn. It is obvious that the velocity with which the steam escapes from the nozzle increases nearly at the same rate as the actuating steam pressure. It is probable that this velocity falls off rapidly from the nozzle outward. Moreover the position of the limit of condensation indicates the height above the nozzle at which the velocity of the escaping

steam outward is just equal to the speed of condensation moving from without inward. Inasmuch, therefore, as the limit of condensation moves toward the nozzle when the pressure increases, the speed of condensation must increase in marked degree with the actuating pressure. This is equivalent to saying that the degree of supersaturation near the nozzle increases remarkably when the actuating steam pressure increases—an important inference which will be utilized in the course of the following work.

Anticipating some of the following results, the above data may be thus interpreted:

The effect of the above variations of pressure on the temperature at a given point near the nozzle would be

4.4° 3.7° 2.6° 1.3° 0.3° 1.8° 2.9° 3.6°

respectively, and the effect of the shifting in the position of the limit of condensation would be

11° 9° 7° 1° 4° 0° 9° 11°,

indicating the preponderating influence in the latter case.

63. Character of the axial distribution.—At this stage of progress it is necessary to determine the law of longitudinal distribution of the temperature of the steam jet as accurately as possible. Looking at the curves of the above plates, particularly Pl. II, the possibility of an hyperbolic equation suggests itself by reason of its simplicity. Thus the equation

$$t - B = \frac{A}{1 + kh}$$

where t is the temperature at a distance h above the nozzle and A , B , and k are constants, has the following properties: At the surface of the nozzle, $h=0$ and $t=A+B$. At a point indefinitely high above the jet, $h=\infty$ and $t=B$. Thus, if the assumptions be made that indefinitely near the nozzle and on the outside the temperature is 100°, $A+B=100$, the value of B should be the air temperature of the room; but it is quite difficult to know what the efficient air temperature actually is in a heated or steam-charged room. A trial suggests $B=14$ ° whereas the measured room temperature below the jet was about 17°. If k be then computed for $A=86$ and $B=14$ from Table 11 (A), as

$$k = \frac{A+B-t}{h(t-B)} \quad \dots \dots \dots (1)$$

the values fluctuate around $k=0.35$. Compared with the observed values of t (Table 11 A), the computed values show discrepancies as large as 5° where the observational errors lie certainly within 1°. The equation is therefore to be dismissed.

Aside from this a direct test can be made on the insufficiency of equation (1) since $\frac{1}{t-B}$ and h if plotted in terms of each other must

give a straight line. As the approximate value of B is given, successive trial values of $t-B$ may be compared. Thus, the shortcomings of (1) become manifest.

64. Exponential constants.—In general it is scarcely probable that a simple equation would express the complicated phenomenon of the jet. I have therefore worked backward from the data of Table 11, as follows: The observations of part A are so made that the corresponding finite increments of temperature Δt and of height ΔH can be easily compared, and the points of the curve are close enough together that $\frac{\Delta t}{\Delta H}$ will be nearly the same as the differential coefficient $\frac{dt}{dh}$, where dt is the infinitesimal increment of temperature corresponding to the increment of height dh , at the axial point h centimeters above the nozzle. Instead of $\frac{dt}{dh}$ it is practically more convenient to take $\frac{dh}{dt}$, because these data lie within more convenient limits. If $\frac{dh}{dt}$ be compared with t graphically, the locus is strongly curved and does not show any marked simplification over the integral locus for h and t . If, however, $\frac{dh}{dt}$ and h be compared, the locus is much flatter than before, so that a simple exponential form can reach it. Put therefore

$$-\frac{dh}{dt} = 10^{Bh} - 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where B is a constant, or

$$\log \left(1 - \frac{dh}{dt} \right) = Bh \quad . \quad . \quad . \quad . \quad . \quad . \quad (2')$$

remembering that $\frac{dh}{dt}$ is negative throughout. Plotting the data of (2) graphically, viz, $\frac{dh}{dt}$ as a function of h , it is seen that the linear character is actually sustained. B may therefore be computed, and the results are given in Table 15, h being the height of the middle of the increment.

TABLE 15.—Comparison of $\frac{dh}{dt}$ and h of Table 11, A , assuming that $\log \left(1 - \frac{dh}{dt} \right) = Bh$.

h	$-\frac{dh}{dt}$	B	h	$\frac{dh}{dt}$	B
0.8	0.090		10.0	0.600	0.0204
1.2	.053	.0187	14.5	0.960	.202
2.2	.125	.232	20.5	1.58	.201
4.2	.250	.231	29.5	2.70	.193
6.7	.390	.199	Mean.	B	0.020

If the points near the nozzle where observation is difficult and uncertain be overlooked, the group of values thus obtained is good enough

to suggest further inquiry. Equation (2) is virtually a differential equation of the second order, or at least can be easily put

$$\frac{d^2h}{dt^2} = B (\ln 10) \frac{dh}{dt} \left(\frac{dh}{dt} - 1 \right),$$

which on integration leads to

$$10^{-Bh} = 1 - 10^{-B(t+A)}$$

or to

$$B(t+A) = -\log(1 - 10^{-Bh}) \quad . \quad . \quad . \quad (3)$$

and thus the differential equation.

$$\frac{dt}{dh} = 1 - 10^{B(t+A)} \quad . \quad . \quad . \quad (4)$$

corresponds to (2).

If in (3), $h = \infty$, then $t = -A$; and thus $-A$ is the temperature of the medium into which the steam is discharged and is approximately known from observation. If $h=0$, $t = \infty$, indicating that the temperatures near the nozzle must be enormously high. Whether or not this is a real insufficiency of equation (3) can not be easily seen, for the temperatures near the nozzle do not lend themselves to accurate observation. The remedy, however, is not far to seek; for if, instead of 2' the equation

$$\log \left(1 - \frac{dh}{dt} \right) = -\log C + Bh \quad . \quad . \quad . \quad (5)$$

be evaluated, the integral will be

$$B(t+A) = -\log(1 - C 10^{-Bh}) \quad . \quad . \quad . \quad (6)$$

in which if $h = \infty$, $t = -A$ as before; and if $h = 0$, $t = -A - \frac{1}{B} \log(1-C)$

and therefore remains finite, remembering that both A and $\log(1-C)$ are inherently negative. It will presently be seen that the agreement with observational values thus obtained is very good.

The convenience of equation (6) is manifest, since both B and C are obtained graphically, and it is merely necessary to compute $-A$, the quantity which symbolizes the efficient atmospheric temperature. The following table shows a satisfactory set of values:

TABLE 16.—Values of $-A$, in the equation $B(t+A) = -\log(1 - C 10^{-Bh})$, when $B = 0.019$, $C = 0.977$.

h	t observed.	$t+A$ computed.	$-A$
<i>Cm.</i>	<i>C.</i>	<i>C.</i>	<i>C.</i>
0.5	83.1	71.38	(11.7)
1.1	76.4	61.17	15.2
1.3	72.6	58.61	14.0
3.2	57.0	43.26	13.7
5.3	48.5	34.08	14.4
8.1	40.7	26.44	14.3
12.0	34.2	19.72	14.5
17.1	28.9	14.20	14.7
23.9	24.6	9.60	15.0
35.0	20.5	5.43	15.1
Mean.		.1	14.54

In this table the values of $-A$ for $h = 1.1, 23.9, 35.0$ cm. are above 15° , but these observations were made in the afternoon, when the room temperature was about 1° higher than in the morning. The remaining observations show a gradual increase of $-A$, due to the same cause that the room temperature was gradually rising, even during the morning. The value of $-A$ for $h = 0.5$ is too low, also easily explained because of the difficulties of measuring temperature near the nozzle where the jet is narrow. Hence if

$$t = -A - \frac{1}{B} \log (1 - C 10^{-Bh})$$

the observations are well reproduced when the constants are

$$-A = 14.66^\circ; B = 0.019; C = 0.977,$$

whence

$$h = \infty; t_\infty = -A = 14.7^\circ$$

$$h = 0; t_0 = -\frac{1}{B} \log (1 - C) - A = 100.8^\circ$$

Both t_0 and t_∞ are virtually predications of equation (6), and the fact that the first lies so near the air temperature and the second so near the normal boiling point of water are the important features of the equation taken

In the same way the other series of data B and C of Table 11 might be discussed. But it is expedient to derive the corresponding curves from the pressure variations found in the earlier tables, and thus to obviate the change of the arbitrary variable for the temperature of the medium.

65. Graphic digest.—Utilizing the constants computed in the earlier paragraph, I have constructed Table 17, in which, together with other data, a full account of the change of temperature, t_{50} , along the axis from the nozzle to a height h , of about a meter above this point, is given. These results are graphically shown in the chart, Pl. III, where (as usual) height in centimeters above the nozzle is the abscissa and temperature in $^\circ C$ the ordinate. The observations are also inscribed for the actuating steam pressure $P = 50$ cm. of mercury, being Table 11, part A, where the temperature just inside of the nozzle is $T = 114^\circ$. Little circles drawn around the points distinguish these observations from other data to be presently explained. The curve for t_{50} is drawn out in full. All the observations coincide with it, excepting the last two perhaps. But these were made when the air temperature was warmer, and their position is therefore in accord with this fact. The enormous fall of temperature within a few millimeters on either side of the nozzle is well shown near the origin of the curve.

TABLE 17.—*Axial distribution of temperature in the steam jet.*

$$t = -A - \frac{1}{B} \log(1 - C 10^{-Bh}); P = 50 \text{ cm.}$$

$$-A = 14.54^\circ; B = 0.019; C = 0.977; T = 114^\circ.$$

$$B' = 0.0204; B'' = 0.0177.$$

h	t_{50}	t'	t''	h	t''	t'	t''
<i>Cm.</i>	<i>° C.</i>	<i>° C.</i>	<i>° C.</i>	40.0	18.8	17.97	19.76
0.0	100.8	94.80	106.80	50.0	17.3	16.63	17.88
1.0	77.0	71.84	82.61	60.0	16.2	.....	.....
2.0	66.2	61.54	71.17	80.0	15.2	.....	.....
3.0	59.0	54.76	63.60	100.0	14.8	.....	14.95
4.0	53.8	49.84	58.03		14.54	14.54	14.54
5.0	49.7	46.04	53.65				
6.0	46.4	42.96	50.08				
8.0	41.2	38.21	44.53				
10.0	37.3	34.62	40.31				
12.0	34.3	.....	.....				
15.0	30.7	28.60	33.07				
18.0	28.0	.....	.....				
20.0	26.5	24.79	28.44				
25.0	23.6	.....	.....				
30.0	21.5	20.34	22.87				
35.0	20.0	.....	.....				

SUMMARY.

$h = 0 \text{ cm.}$	$\frac{dt}{dp} = 0.120$
10	.057
20	.037
30	.025
40	.018
50	.013

66. *Effect of steam pressure.*—In Table 8 the values of $\frac{dt}{dp}$ lie between 0.09 and 0.07; but the temperature of the medium is not given. In Table 9 these values lie between 0.06 and 0.11. A relation to the height (H) above the nozzle can not be made out. The medium is at 26° to 27° C. In Table 10, $\frac{dt}{dp}$ is usually 0.12 in value, though there is a jump in the last of the values to 0.20. The medium is usually 17° to 18° .

All that can be inferred from this is an increase of the pressure coefficient, when the air temperature is colder, and it may be roughly rated as a decrease of 0.0025 for $\frac{dt}{dp}$ for each degree of increase of the temperature of the medium. Throughout this paper the temperature of the medium does not enter sharply, because I worked in an unequally heated room. The heat radiated by the jet introduces a discrepancy.

Suppose, temporarily, that $\frac{dt}{dp} = 0.12$, since the media in tables 10 and 11 were nominally at the same temperature, and let the variation of $\frac{dt}{dp}$ with the height H of the point above the nozzle be overlooked.

Then the temperature at every point of the axis of the jet is 0.12° colder for each centimeter of decrease of pressure. The effect of a given increment of pressure is therefore to shift the position of the curve (t and h), as a whole, in a vertical direction. This result is the closest approach to the actual state of the case which my observations enable me to make. But the solution can not be correct, since it involves thermal shifting of the asymptote ($h = \infty$), and the results for radial distribution of temperature (section 60) show clearly enough that the curve must terminate on all sides in the temperature of the air medium.

I have endeavored to get around these difficulties in the following way. Suppose, as before, that initially $\frac{dt}{dp} = 0.12$, but that it is a variable quantity, falling off gradually to zero as the height above the nozzle increases. There is some evidence of this in Table 9, but apart from data the result is necessary. Solving the above equation for $h=0$

$$t_0 = -A - \frac{1}{B} \log(1-C)$$

where t_0 is the temperature just outside of the nozzle, and A , B , and C are constant, $-A$ the temperature of the medium (14.54°) retains its former value, so that the effect of pressure in changing t_0 can only be represented by changes of B and of C . The effect on t produced by changes of B and C may be found by differentiation; but the results are involved and it is more satisfactory to make an actual computation.

Since the curve of the chart corresponds to $P=50$ cm. of mercury, let the curves t' for $P=0$ and t'' for $P=100$ be computed. The initial effect of pressure is therefore -6° and $+6^\circ$, respectively, so that

$$t' = 94.8^\circ, t_{50} = 100.8^\circ, t'' = 106.8^\circ,$$

and if at first C be considered constant (0.977 as above), and B only variable, the results $B' = 0.204$ and $B'' = 0.0177$ are obtained.

The data so computed are also given in Table 17. They are distinguished in the chart by the aid of dashes pointing, respectively, to the left upward and to the right upward.

The first result obtained in this way is important. Remembering that t' to t_{50} and t_{50} to t'' correspond to equal steps of pressure (50 cm. of mercury each), and that $P'' - P' = 100$ cm. is much above the interval of observation, the occurrence of t_{50} as a mean between t' and t'' shows the above linear variations of temperature and pressure (sections 57-58) to be reproduced. The discrepancy is rarely above 0.1° , which would easily escape observation. Thus far the postulate of B variable with pressure accords with the observations.

If, however, the data for $\frac{dt}{dp}$ be computed (see end of Table 17), they decrease with h rather more rapidly than the observations warrant. I have shown this in the chart near the bottom, where the observations of Table 9 are shown by crosses, these being the only ones available.

TABLE 18.—Axial distribution of temperature in the steam jet.

$$t + A = -\frac{1}{B} (1 - C' 10^{-Bh}),$$

$$C' = 0.977; C'' = 0.982; C''' = 0.970.$$

$$B = 0.019; A = 14.54.$$

h	t_{80}	t''	t'	h	t_{80}	t''	t'
<i>cm.</i>	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	<i>cm.</i>	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$
0	100.8	106.80	94.80	10	37.3	37.52	37.03
1	77.0	78.74	74.75	15	30.7	30.82	30.54
2	66.2	66.99	64.82	20	26.5	26.58	26.38
3	59.0	59.71	58.04	30	21.5	21.57	21.45
4	53.8	54.32	53.04	40	18.8	18.82	18.77
5	49.7	50.16	49.13	50	17.2	17.22	17.19
6	46.4	46.72	45.88	100	14.8	14.83	14.83
8	41.2	41.46	40.84	∞	14.5	14.54	14.54

Again, let B in equation be constant and C the variable. Then the values

$$C' = 0.970, C = 0.977, C'' = 0.982$$

are obtained as before, from which the data of Table 18 are computed. They are distinguished in the chart by points with dashes to the right and left downward. It is seen that with the exception of points near the origin, the curves t' and t'' run rapidly into t_{80} , so that even as near the nozzle as $h = 1$ cm., they could not be easily distinguished with certainty.

Hence it must be possible to vary B and C simultaneously in such a way as to produce contrary effects on t , and a slower decrease of $\frac{dt}{dp}$ than was obtained in Table 17 will then result. I will not, however, carry this out, since the data necessary to test the results are not in hand, but will conclude with the following general remark:

67. Conclusion.—All the observations go to show that the temperature of the jet changes with the actuating steam pressure quite up to the plane of the nozzle. In the latter case when $P = 0$, the temperature should be $t_0 = 100^{\circ}$ (supposing the barometer normal). If, therefore, the equation

$$t + A = -\frac{1}{B} \log (1 - C 10^{-Bh})$$

be taken, whence

$$t_0 + A = -\frac{1}{B} \log (1 - C),$$

and if the effect of the medium be left out of consideration (supposing its temperature constant), then the axial distribution of temperature for $P = 0$ should commence with $t = 100^{\circ}$ at $h = 0$, and all other curves of the family lie bodily above this in proportion as P is greater. In other words, if $\mu = \frac{dt}{dp}$,

$$100 + \mu P + A = -\frac{1}{B} \log (1 - C)$$

and the problem then consists in so determining B and C that the observations are reproduced. The values of the present paper may be regarded as approximations.

I have proceeded in the above purely experimental way because the theoretical side of the problem involves formidable difficulties. So far as I have gone the phenomena seems to lend itself to a determinate experimental solution.

CHAPTER V.

DISTRIBUTION OF TEMPERATURE IN THE COLOR TUBE.

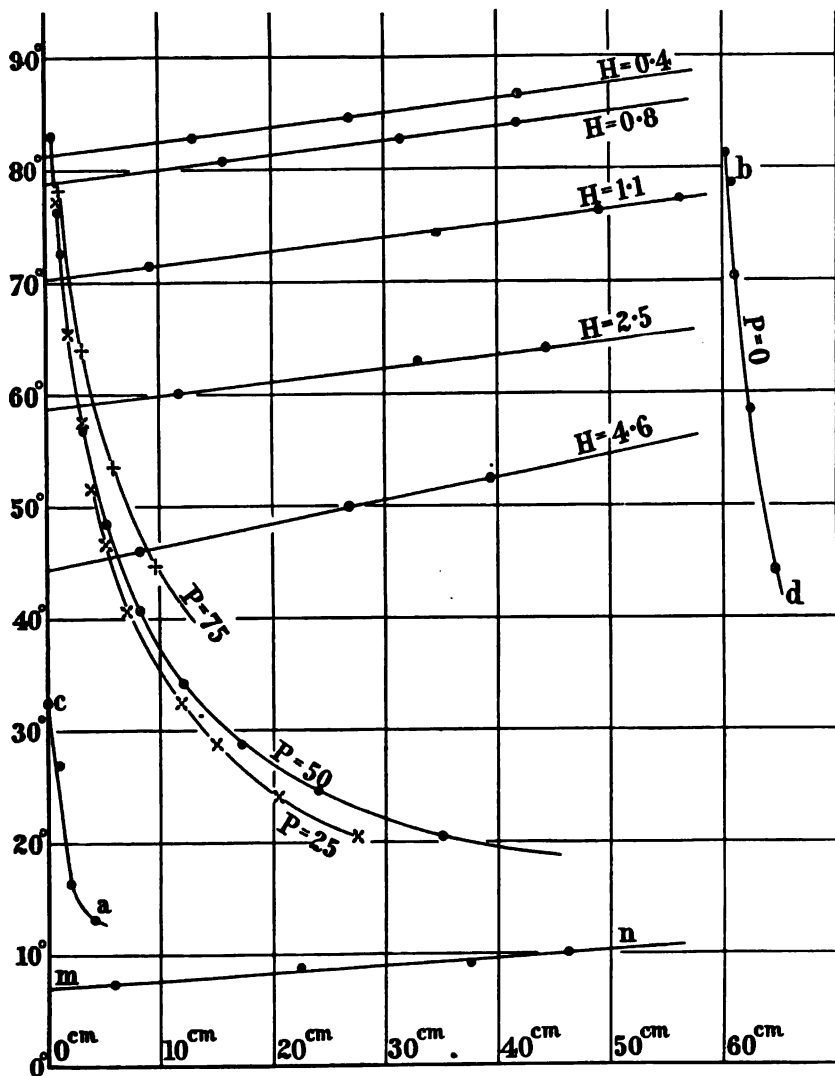
68. *Points of view.*—In the preceding chapter the effect of the temperature of the medium on the thermal topography of the steam jet was merely stated inferentially. I shall in the present chapter endeavor to obtain data of a more specific character. Moreover, the effect of the tube on the temperatures of the inclosed jet is to be compared with the case of the free jet, both in regard to the axial distribution of temperature as well as to its variation at any point with pressure. Results so obtained will apply more directly to the colored cloudy condensation within the tube.

69. *Temperature. Axial distribution.*—The first point at issue is the change of temperature along the axis of the color tube. It is clear at once that inasmuch as the opportunities of radiation and continued mixture are largely cut off, the change of temperature must be more gradual than was observed for the free jet.

To make these measurements, five holes were drilled into the color tube at suitable distances apart, and each hole provided with a short tubulure so that it could be closed with a cork. When observations were to be made at any point the cork was withdrawn and the junction of the thermocouple (sections 52, 53) there inserted. To obtain the present data it was therefore merely necessary to move the couple from hole to hole upward. As a rule, there was little difficulty in securing an axial adjustment of the couple, except near the nozzle, where the narrowness of the jet introduced discrepancies of the kind already sketched above. (Sections 55, 56.)

The hot junction was kept at the boiling point of water by the aid of an apparatus for continuous ebullition. Computations were made as before. (Section 54 et seq.)

Table 19 shows the results of these measurements, H denoting the height of the junction above the nozzle of the jet and t the temperature there observed. The pressure (P) actuating the jet was kept at about 30 cm. of mercury, and fluctuated within about 1 cm. The temperature (θ) of the inflowing air had the mean value of 17° C. though a fluctuation within 1° C. was unavoidable. It will presently be seen that the discrepancies introduced by both these irregularities are small. A source of greater annoyance is the hot water, which condenses in the jet and is squirted out against the junction from time to time. Observations must therefore be made when the jet is flowing smoothly. In the table, values of H near the nozzle are put in parenthesis because of the uncertainty of this measurement.



Curves H showing the increase of temperature (ordinates) for the different pressures (abscissas, cm. of Hg) actuating the steam jet, at different heights (H in cm.) above the nozzle.
 Curves P showing the values of the temperature (ordinates) at different heights above the nozzle (abscissas in cm.) when the actuating steam pressure P has a fixed value.
 Curve c a r showing the radial distribution of temperature (ordinates) in terms of the radius (r in cm.) of a right section, where the visible width of the section is $2r = 4$ cm.
 Curve m n showing the difference of temperature (ordinates magnified 10 times) between the steam box and the inside of the nozzle, when pressure (abscissas cm. of Hg) varies.

TABLE 19.—*Longitudinal thermal distribution in the color tube.* $P = 30 \text{ cm. } \theta = 17.1^\circ \text{ C.}$

H	t	H	t
<i>Cm.</i>	$^\circ\text{C.}$	<i>Cm.</i>	$^\circ\text{C.}$
46	38.2	(1)	82.0
34	39.2	(0.4)	97.0
20	40.5	46.0	39.0
8	44.7		

70. Digest and chart.—The values of Table 19 are platted in the chart, Pl. IV, curve *a b*, the temperatures being the ordinates, and the heights above the nozzle the abscissas. To bring out the nature of this curve I have also platted the corresponding data *c d*, obtained in the preceding chapter, for the axial distribution in the free jet. (Section 59.) Thus, so far as the evidence goes, one may assume that within the first 5 cm. of height above the nozzle the two curves coincide. Within this distance the jet retains its filamentary outline. Beyond the stated distance, however, the curves diverge remarkably, the one (*a c b*) for the inclosed jet soon reaching a horizontal asymptote, more than 20° hotter than the other, *a c d*. If the color tube were quite nonconducting, even a sharper inflection would characterize *a c b*, as is proved by the higher temperature of the second of the two points for $H = 46 \text{ cm.}$ in Table 19

From a comparison of the two curves in question the following important deduction may be drawn, remembering that the liquid particles are formed within a few centimeters above the nozzle: (1) Throughout those parts of the inclosed steam jet within which the colored cloudy condensation originates the axial distribution of temperature may be regarded as identical with the corresponding case of a free steam jet, *cet par.*; (2) Throughout the remainder of the jet (i. e., in those parts of the color tube in which the water globules are suspended after being formed) the temperature is approximately constant. It is for this very reason that the color tube presents a promising means of studying the gradual growth of water globules, in the manner already stated. (Section 23.)

71. Effect of pressure.—If the position of the junction of the thermocouple (H) be fixed and the temperature (θ) of the inflowing air be kept constant, then the effect of the actuating steam pressure (P) on the distribution of temperature (t) within the tube is observable. Again, if for constant values of P and H , θ be varied the effect of air temperature on the thermal distribution (t) will follow.

The data (t) obtained for both of these cases are given in Table 20, those on the left corresponding to constant values of H (height above the nozzle), those on the right to constant values of the temperature θ of the inflowing air. T denotes the temperature of the steam in the steam box, before issuing at the nozzle, and is computed from P . As before, the hot junction of the thermocouple was in the boiling-point apparatus.

TABLE 20.—*Thermal distribution in the color tube, varying with steam pressure and air temperature.* $H = 0.4$ cm. $\theta = 19.4^\circ$.

P	T	t	P	T	t
<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$	<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$
24.9	108.2	97.0	38.3	111.7	97.6
50.0	114.7	98.9	13.2	104.4	96.2
74.7	120.3	100.7	5.4	101.8	95.8
60.5	117.2	99.7			

 $H = 0.4$ cm. $P = 29.9$ cm. $T = 109.5^\circ$.

θ	t	θ	t	θ	t
$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$
28.3	96.5	37.0	96.2	24.9	95.5
29.0	98.4	32.5	96.1	22.3	95.5
36.6	98.3	32.0	95.5	37.2	95.8

 $H = 8$ cm. $\theta = 20.8^\circ$.

P	T	t	P	T	t
<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$	<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$
13.6	104.6	41.5	83.0	122.1	42.7
29.3	109.4	41.6	72.0	119.7	42.4
43.0	113.1	41.8	50.3	104.8	42.2
63.7	117.8	42.4			

 $H = 8$ cm. $P = 30.5$ cm. $T = 109.6^\circ$.

θ	t	θ	t	θ	t
$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$
20.8	41.6	29.9	43.4	37.6	46.0
28.3	43.0	37.3	46.4		

 $H = 20$ cm. $\theta = 17.7^\circ$.

P	T	t	P	T	t
<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$	<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$
10.4	103.5	38.1	70.5	119.4	39.4
25.2	108.3	38.7	44.1	113.4	39.2
48.2	114.4	39.5			

 $H = 20$ cm. $P = 31.8$ cm. $T = 110.1^\circ$.

θ	t	θ	t	θ	t
$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$	$^\circ C.$
17.5	38.5	37.3	43.6	22.0	39.2
25.5	39.3	29.7	40.7		

 $H = 34$ cm. $\theta = 16.4^\circ$.

P	T	t	P	T	t
<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$	<i>Cm. Hg.</i>	$^\circ C.$	$^\circ C.$
20.3	106.7	37.3	59.2	116.8	38.7
47.2	114.1	38.5	31.7	110.1	37.7
76.3	120.6	39.2			

TABLE 20.—*Thermal distribution in the color tube, varying with steam pressure and air temperature—Continued.* $H=34$ cm. $P=31.2$ cm. $T=109.8^{\circ}$.

θ	t	θ	t	θ	t
$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$
16.4	37.7	36.7	43.8	22.5	39.4
26.0	39.4	29.1	40.4		

 $H=46$ cm. $\theta=17^{\circ}$.

P	T	t	P	T	t
<i>Cm. Hg.</i>	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	<i>Cm. Hg.</i>	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$
15.2	105.2	38.3	79.8	121.2	39.3
29.7	109.5	38.4	63.3	117.8	39.0
48.5	114.4	39.3			

 $H=46$ cm. $P=33.4$ cm. $T=110.4^{\circ}$.

θ	t	θ	t	θ	t
$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$	$^{\circ}\text{C.}$
16.7	37.7	36.5	43.6	20.1	38.4
26.8	39.7	29.7	40.4		

Turning first to the values for constant H and θ and variable P , the observations may be inserted in the chart Pl. IV, temperature (t) being laid off vertically and pressure (P) horizontally. The air temperature, θ , and the height, H , above the nozzle, are inscribed on each curve.

As before, sections 57, 58, these curves are straight lines, and they become rapidly crowded together (conformally with the results of the preceding paragraph) as H increases. The data may easily be summarized by giving the slopes $\frac{dt}{dp}$ for each case, as has been done in Table 21.

TABLE 21.—*Color tube temperatures, changing with pressure only.*

H	θ	$\frac{dt}{dp}$	H	θ	$\frac{dt}{dp}$
<i>Cm.</i>	$^{\circ}$		<i>Cm.</i>	$^{\circ}$	
0.4	19	0.072	34	16	0.035
8	21	0.020	46	17	0.025
20	18	0.025			

Near the nozzle, therefore, where the temperature of the jet is presumably like the corresponding free jet, the pressure coefficient $\frac{dt}{dp}$ is also of the order of those found in the preceding chapter. Above this the value of the pressure coefficient falls off with great rapidity, so that throughout almost the whole length of the color tube it retains a constant value of about $0.026 = \frac{dt}{dp}$.

Hence the effect of changes of the actuating steam pressure on the temperature of the tube are of secondary importance, and the reason for this is to be found in the fact that the air current increases nearly proportionally to the steam current.

Incidentally it is interesting to note again the tremendous fall of temperature, $T - t$, observed when $H = 0.4$ cm. Thus within the fraction of a centimeter temperatures decrease as much as 20° C. Within 8 cm. above the nozzle they have decreased as much as 80° C., showing the even more marked effect of admixture with air.

72. Effect of air temperature.—The second part of Table 20 is now to be discussed in a way similar to the preceding case. Since steam pressure P and height H above the nozzle are now constant, the jet temperature (t) may be laid off vertically and the air temperature θ horizontally. To obviate confusion or crowding of the curves, it is desirable to shift the curves, retaining, however, the same scale as before. This is done in

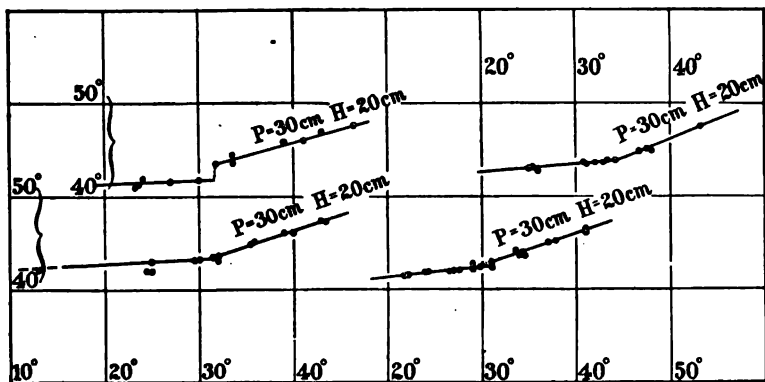


FIG. 27.—Curves showing the temperature in the axis of the color tube.

the chart, Pl. IV, where the values of H and P are given for each curve.

The first of these curves (for $H = 0.4$ cm.) differs in a marked way from the others. It can not be said to possess either curvature or slope, and its position is high (55°) above the other curves. If a slope be conceded, its value must be less than $\frac{dt}{d\theta} = 0.02$, proving that for points near the nozzle of the jet the observed cooling is largely (almost wholly) adiabatic. This also agrees with the inferences of the preceding paragraphs.

The remaining curves for $H = 8, 20$, etc., are all crowded together in the region of $t = 40^\circ$; and, singularly enough, they are well indicated broken lines, with the breaks at nearly the same place ($26^\circ = \theta$). This behavior is at first sight quite puzzling, and, without passing hasty judgment on the matter, I determined to continue the experiments under altered conditions. For this purpose I put a second steam drum into the hot-air pipe, section 30, fig. 14, so that the range of variation of

θ might be sufficiently increased. Moreover, observations were now made both with a thermocouple as well as with a small bulb thermometer. The results are contained in Table 22, the notation being as before. Plating these values in the chart, fig. 27, in the same way as before, the broken lines are obtained in both instances, with the marked exception, however, that the break now occurs at a considerably higher temperature, somewhere between $\theta=30^{\circ}$ – 33° . These observations gave me a clue as to the cause of the curious behavior obtained, for the rate at which the air is supplied by the influx pipes, even if they are all of the same diameter, will depend materially on the length and the elbows in these pipes (cæteris paribus). Now the hot-air pipes are not only larger but more crooked than the cold-air pipe. Hence there can be no doubt that less air is supplied when the passage takes place mainly through the hot pipes than when it flows mainly through the cold pipes. It follows that as θ is greater, the amount of air supplied, and therefore its cooling influence, is proportionately less. There will, therefore, be a different rate of heating before and after the cold-air pipe is shut off. This is what the curves (P , H , chart) actually show, and the break changes with the obstructions in the hot-air pipe.

TABLE 22.—*Thermal distribution in the color tube varying with air temperature.*

$H=20$ cm.; $P=30$ cm. Hg.

θ	t^1	θ	t^1	θ	t^1	θ	t^1
° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
23.2	41.0	25.0	43.0	25.0	43.0	21.8	41.5
23.5	41.4	25.0	43.0	25.0	43.0	21.9	41.5
27.0	41.6	30.7	43.5	29.5	43.1	26.5	42.0
30.0	41.8	32.0	43.6	30.0	43.3	27.0	42.0
33.5	44.5	32.8	43.6	31.5	43.5	27.5	42.1
39.0	45.9	34.1	43.9	32.0	43.2	29.0	42.3
41.0	46.0	38.0	45.0	32.0	43.5	29.8	42.5
43.0	46.9	43.1	47.5	35.5	45.0	31.0	43.0
46.4	47.7	37.4	45.1	35.7	45.2	33.5	44.2
46.4	47.8	36.7	44.9	39.0	46.2	34.2	44.0
33.5	43.6	33.2	43.9	40.0	46.2	37.0	45.2
31.7	43.6	31.0	43.5	40.0	46.0	37.8	45.3
24.0	42.0	25.9	42.6	43.0	47.6	41.0	36.2
				43.0	47.5	41.0	36.3
				25.0	42.0	34.5	43.7
				24.5	42.0	34.0	43.7
						31.0	42.5
						30.0	42.8
						29.0	42.8
						24.2	42.0
						24.0	42.0

¹ Thermocouple.

² Thermometer.

To verify this, I shut the cold-air pipe off entirely and changed the temperature of the hot air by passing more or less steam through this coil. Curves thus obtained showed greater regularity, and the break was nearly eliminated. Finally, by comparing these results with the datum obtained directly when the hot pipe is shut off and the cold one open, a difference of several degrees of t corresponded to a given value of θ for the two cases.

This shows the delicate balance which must exist between the temperature of the color tube at any point and the constants (temperature, flow, etc.) of the air supply. Thus in the chart, fig. 27, the two parts of the curves may actually fail to coalesce when the velocity of the air current without change of temperature is altered in an abrupt way. It does not seem probable, therefore, that the point of inflection can be referred to a special condensation phenomenon in the jet, an inference which I was at first inclined to countenance.

73. Mean coefficients.—These experiments point out certain shortcomings in the apparatus (fig. 14), for it now appears clearly enough that for a given influx hole, say 2 inches in diameter, the hot and cold conveyance pipes should be larger than 2 inches. They also show that any statement as to the effect of the temperature of the inflowing air on the temperatures of the color tube is incomplete without a qualifying statement as to the amount of air supplied—a state of things which one might easily anticipate, but I was not prepared for so large a discrepancy as that actually observed.

To obtain a datum for the effect of the temperature of the inflowing air in case of an influx pipe about 1 meter long and 2 inches in diameter, the means of the two branches of the curves Pl. IV and fig. 27 may be taken, for the manipulation was as follows: At the outset the cold valve was open and the hot valve closed. The latter was then gradually opened (increasing the air supply as well as the air temperature) until quite open. Then the cold valve was gradually closed (decreasing the air supply and increasing the air temperature) until quite shut off. The two branches of the curves thus represent symmetrical cases, assuming that when both valves are open at least as much air is furnished as can flow through the given influx pipe.

The following table contains the results:

TABLE 23.—*Mean coefficients for the effect of air temperature.*

<i>P</i>	<i>H</i>	$\frac{dt}{d\theta}$	Mean $\frac{dt}{d\theta}$	<i>P</i>	<i>H</i>	$\frac{dt}{d\theta}$	Mean $\frac{dt}{d\theta}$
30	8	.35	-----	30	20	.04	.16
						.28	
32	20	.10	.24	30	20	.08	.25
		.37				.42	
31	34	.19	.27	30	20	.07	.20
		.36				.32	
33	46	.07	.29	30	20	.11	.23
		.51				.35	

Thus the temperature at any point of the color tube increases about 0.2° to 3° for each degree of increase of the temperature of the inflowing air, and throughout a distance of 8 cm. to 50 cm. above the nozzle. Near the nozzle (< 0.4 cm. above it), where there is no mixing, the effect is nil. It is a maximum near the top of the tube, where mixture is most complete.

Summary.—With these experiments I have thrown about as much light on the color phenomena, seen by the aid of steam jets, as lies within the reach of this purely experimental method. A part of the work could have been refined, but such refinement would not, in my judgment, lead to any essential novelties, unless they relate to the delicate question of the temperature and saturation of the medium into which the jet is discharged.

All the evidence goes to show that the first stages of cooling are adiabatic, for the temperature of points of the steam jet lying near the nozzle is nearly independent of the temperature of the medium into which the jet discharges (section 72), so far as examined. The amount of cooling which takes place in this way is noteworthy, as well as the suddenness with which it takes place. There is little doubt in my mind that this adiabatic cooling would actually carry the jet to the point of condensation, even if the discharge took place into an absolutely dust-free medium. Thus the appearance of the jet in this case suggests itself as a means of obtaining collateral evidence, and the experiment is soon to be made. (Section 62.)

The second stage of cooling is due to intermixture with air. It is promoted by turbulent motion within the jet, and hence a rough nozzle (sections 44 to 46) or dust nuclei in the medium (section 38) precipitate condensation, so that the case of a perfectly smooth jet in a dust-free medium is again of interest. Here it seems that condensation would at first result as the direct effect of adiabatic cooling, and at the height of the condensation limit the molecules themselves became condensation nuclei.

As long as the cooling is merely adiabatic, many of the conditions¹ involved are open to computation. Let G be the entropy of a x kilograms of steam in intimate contact with $(1-x)$ kilograms of water, both at the same absolute temperature T , at which the specific heat of water is C and the latent heat of steam r . Then

$$G = \frac{rx}{T} + C \ln T \dots \dots \dots (1)$$

where x is conveniently fractional.

If therefore there were no lag phenomenon or no supersaturation, this equation is sufficient to show the amount of water which would separate out of the jet at each of the stages of adiabatic cooling. Take, for example, the case of Table 19 ($H=0.4$ cm.), where the steam arrives at a pressure of $P=75$ cm. and an absolute temperature of $120^\circ + 273^\circ = 393^\circ$ C., and at about 0.4 cm. above the nozzle is already cooled down to $100 + 273 = 373^\circ$ C. of absolute temperature. Just before entering the nozzle the mixture is wholly vapor, and therefore

$$x=1; r=522; T=393^\circ; C=1; \text{ (nearly)}$$

whence $G=7.302$ as the entropy per kilogram of escaping steam.

¹Cf. Bertrand: *Thermodynamique*, Chap. x, Paris, 1887.

At the distance 0.4 cm. above the nozzle this entropy can not have changed, in view of the rapidity of efflux. Hence $G = \text{constant} = 7.302$, while

$$T = 373^\circ; r = 536; C = 1.$$

Hence

$$x = (G - \ln T) \frac{T}{r} = 0.960$$

$$(1 - x) = 0.040$$

or there must be about 40 grams of suspended water globules in each kilogram of the mixture of steam and water, in order to quite relieve the strain of supersaturation. It is instructive to trace this phenomenon further, supposing the steam which arrives at a temperature of 120°C. to be successively cooled in adiabatic stages of 20° . The following table contains the results.

TABLE 24.—*Condensation due to adiabatic cooling.*

[Steam initially at 120° . Entropy per Kg., 7.30.]

Cooled to	Vapor present.	Water condensed.	Cooled to	Vapor present.	Water condensed.
$^\circ \text{C.}$	Kg.	Kg.	$^\circ \text{C.}$	Kg.	Kg.
120	1.00	0.00	40	0.84	0.16
100	.96	.04	20	.80	.20
80	.92	.08	0	.76	.24
60	.88	.12	-20	.72	.28

Hence, if there were no cooling by convection or mixture, the steam discharged into a medium of ordinary temperatures would continually condense. In general, however, the equation (1) is such that the quantity of vapor x , regarded as a function of T , must pass through a minimum. Nevertheless, the steam jet, in which there is both condensation and evaporation, owes the latter property to the solutional effect of the admixed air. Adiabatic expansion can alone increase the condensation, always supposing that the jet is initially vapor.

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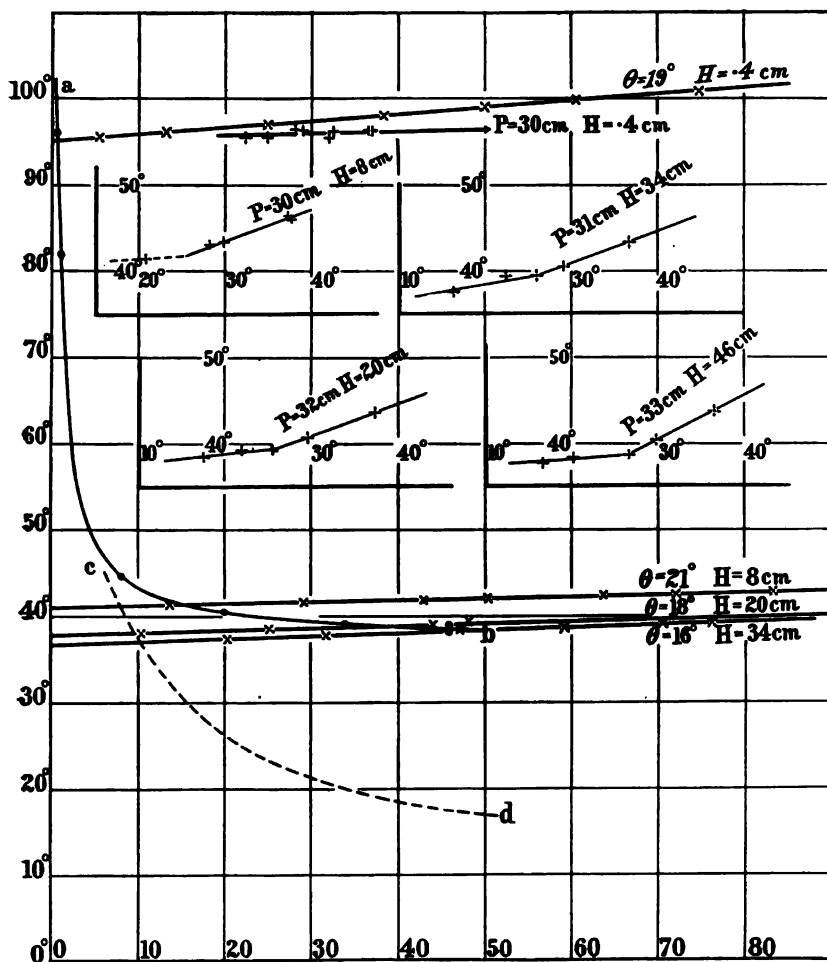


Chart showing the axial temperature in the color tubes, viz:

Curve *a c b*, axial distribution of temperature (ordinates) in terms of height (abscissas in cm.) above the nozzle.

Curve *a c d*, same for a free jet.

Curves θ , H , change of temperature (ordinates) at a given point (H) in terms of the actuating steam pressure (abscissas in cm. of mercury).

Curves P , H , change of temperature (ordinates) at a given point (H) in terms of the temperature of the inflowing air (abscissas in $^\circ\text{C}$).

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WEATHER BUREAU.

14 SEP 1896

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AND DURING TRANSPORTATION,

AND

METHODS OF PROTECTION FROM THE SAME.

PREPARED UNDER THE DIRECTION OF

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LETTER OF SUBMITTAL.

WASHINGTON, D. C., *June 1, 1896.*

SIR: I submit herewith for publication a revised copy of the circular of information entitled *Temperatures Injurious to Food Products in Storage and During Transportation, and Methods of Protection from the Same*. The paper includes the matter contained in the pamphlet entitled, *Protection of Fruits, Vegetables, and Other Food Products from Injury by Heat or Cold During Transportation*, to which has been added valuable information as to the temperature conditions favorable to the safe-keeping of food products in storage, the slaughtering of cattle and hogs with a view to the subsequent preservation and curing of the meat, and suggestions as to how to best utilize the weather reports in connection with the safe storage and shipment of food products. It is proper to state that the suggestion which led to the preparation of the pamphlet referred to was received from Mr. A. F. Sims, Observer Weather Bureau, Albany, N. Y.

The chief credit for the preparation of this paper is due to Mr. H. E. Williams, Chief of the Forecast Division, who prepared the circular calling for the information, and edited and arranged the matter.

Very respectfully,

H. H. C. DUNWOODY,
*Assigned to duty as Acting Assistant Chief,
In charge of Forecast Division.*

WILLIS L. MOORE,
Chief of Weather Bureau.

CONTENTS.

	Page
Object of the bulletin.....	7
Objects to be attained in the shipment of perishable fruit.....	7
Temperatures for shipping perishable goods.....	7
Food products in storage.....	13
Temperatures favorable for slaughtering cattle and hogs and the preservation and curing of the meat.....	15
The use of the weather reports in connection with the safe storage and shipment of food products.....	17
The lowest and highest temperatures to which perishable goods may be subjected without injury under the conditions stated.....	19



TEMPERATURES INJURIOUS TO FOOD PRODUCTS IN STORAGE AND DURING TRANSPORTATION, AND METHODS OF PROTECTION FROM THE SAME.

The object of this bulletin is to furnish information regarding the temperatures that are injurious to food products and other perishable articles, under different conditions and during shipment, and to suggest methods of protecting the same from extremes of heat and cold. This information is largely a compilation of the opinions of merchants and shippers in all parts of the country, which were received in reply to a circular letter sent out by the Weather Bureau, and it is thought that the bulletin will prove of interest and value to the public generally.

The goods claimed as perishable, and for which protection from excessive heat or cold is necessary are, all fruits and vegetables, milk, dairy products, green meats, poultry, game, fish, oysters, clams, malt and hop liquors, wines, mineral waters, wet, canned, or bottled groceries, ink, mucilage, proprietary medicines, and liquid drugs having water instead of alcohol for a base.

In the transportation of perishable freight there are three primal objects to be attained :

1. The protection of the shipment from frost or excessive cold.
2. The protection of the same from excessive heat.
3. The circulation of air through the car, so as to carry off the gases generated by this class of freight.

TEMPERATURES FOR SHIPPING PERISHABLE GOODS.

The temperatures at which perishable goods are liable to damage vary greatly with different commodities, their condition when shipped, how long they may be in transit, whether they are kept continually in motion, etc.

The degree of cold to which these goods may be subjected without injury depends on the time the shipment will be on the road; also, whether it will be unloaded immediately upon arriving at its destination, or allowed to stand some time. The direction of shipment, whether toward a cold area or away from it, and the duration of the exposure, as well as the intensity of the cold, must be considered.

Shippers and agents concur in the statement that danger in transportation by freezing can be practically eliminated by the shipment of produce by modern methods; the lined car suffices in spring and

autumn, and usually during the winter, while in extreme weather specially built cars are used. The temperature of the produce when put into the car is quite a factor to be observed. If it has been exposed to a low temperature for a considerable time before, it is in a poor condition to withstand cold, and the length of time so exposed should be taken into account. It is also claimed that a car load of produce, like potatoes, will stand a lower temperature when the car is in motion than when at rest.

In ordinary freight cars perishable goods can be shipped with safety with the outside temperature at 20° , and in refrigerator cars at 10° . In the latter, these goods may be safely shipped with a temperature outside of from zero to 10° below, if the car is first heated, and at the end of the journey the goods are immediately taken into a warm place without being carted any great distance. The better class of refrigerator cars will carry all perishable goods safely through temperature as low as 20° below zero, provided they are not subjected to such temperatures longer than three or four days at a time, while with the ordinary refrigerator cars temperatures of zero are considered dangerous, especially if the goods they contain be of the most perishable kind.

Goods at a temperature of 50° to 60° , packed in a refrigerator car, closed, have been exposed to temperatures 10° to 20° below zero for four and five days without injury.

Shipments of tropical fruits in ordinary freight cars cannot be safely made when the temperature is below 30° , except in cases where the distance is so short as not to expose them for a longer period than twelve hours, and even then they must be carefully packed in straw or hay. The hardier northern fruits and vegetables can be safely shipped in a temperature of about 25° , but the same protective measures must be employed as in the case of tropical fruits when lower temperatures prevail. Long exposure to temperature of 20° is considered dangerous to their safety. Foods preserved in cans or glass should not be shipped any distance when the temperature is below the freezing point.

Fish are shipped by express and also by freight. When shipped by express they are packed in barrels with ice. When shipped by freight they are packed in casks holding 600 pounds each, or in boxes on wheels, holding about 1,000 pounds each. When shipped in car-load lots they are packed in bins built in the car and thoroughly iced. The amount of ice supplied should equal one-half the weight of the fish. No accurate observations have been kept of the exact temperature fish keep best in, but it is found that they keep in better condition when the temperature of the box in which they are stored, with ice, is about that of melting ice. Under favorable conditions fish remain sound and marketable for thirty days after being caught and packed in ice. The entrails of fish should be removed before shipping, as they are the parts that most readily decay, and taint the

flesh of the fish. This is especially necessary in shipping long distances.

Shucked oysters, shipped in their own liquor in tight barrels, will not spoil if frozen while in transit. Thick or fat clams or oysters will not freeze as readily as lean ones, as the latter contain much more water. Oysters will not freeze as readily as clams. It is safer when oysters or clams in the shell are frozen to thaw them out gradually, in the original package, in a cool place. Clams and oysters in transit through a snowstorm will not freeze as readily as when the weather is fair and a stiff wind prevails.

In freezing weather oysters and clams are shipped in tight barrels lined with paper.

Beer can be shipped at an outside temperature of 10° , if placed in a refrigerator car and the kegs packed in hay or sawdust, and fresh stable manure, the packing being 6 inches or more all around. Bottled beer that has passed through a low temperature during transit should be placed in a cellar and allowed to regain a normal temperature slowly, otherwise it is liable to spoil.

Mineral waters and nonalcoholic ales cannot be exposed to a temperature below 30° for any considerable time without injury.

As a rule, truckers will not haul vegetables to the cars for shipment when the temperature reaches 20° , or lower, and in no case when it is near 32° , if raining or snowing.

Articles shipped from the North to the South during winter should be in a perfectly dry condition.

In shipping early vegetables to a northern market from the South, for distances requiring more than forty-eight hours to cover, open-work baskets, slatted boxes, or barrels with openings cut in them, should be used to allow a circulation of air.

It is not safe to ship olives in any car, unless heated artificially, when the temperature is below 25° .

In shipping green meats the almost universal practice is to ship in refrigerator cars where the temperature can be maintained at any desired degree, a temperature from 36° to 40° being considered the best.

Fresh beef for shipping should be chilled to a temperature of 36° , although under favorable conditions it will arrive in a good state if chilled to only 40° . The cars should be at the same temperature as the chill rooms, and it is considered very important to have an even temperature from the time the beef is taken from the chill room until its arrival at its destination.

In shipping long distances in summer, it is necessary to re-ice the cars, the frequency depending on the prevailing temperature, so that no fixed rule can be given. In winter, the temperature is kept up to 36° by means of stoves or oil lamps.

If refrigerator cars are not used, the meat should be wrapped in

burlaps, and the carcasses hung so as not to touch each other. With an outside air temperature of 50° , or below, in dry weather, meat that has been thoroughly cooled will keep a week if shipped in an ordinary box car. Pork is injured more quickly by high temperature than other meats, and greater care should be taken with it in storing and shipping. Sudden changes in temperature of from 10° to 20° are very injurious to green meats, and should be provided against when possible.

Poultry, if shipped at a temperature of 50° and up, should be packed in ice and burlaps; if under 50° , in dry weather, no extra precautions are needed.

Milk for shipping requires great care to prevent souring; it should be reduced after drawing, to a temperature of 40° , which extracts the animal heat. It should never be frozen, as it becomes watery and inferior in quality when thawed out.

Butter should not be frozen unless it is to be used soon after thawing; it freezes at 15° , and when thawed becomes strong quickly.

It is important to note that in shipping fruits, etc., many of the precautions taken in packing to keep out the cold will also keep in the heat, and there is really more danger in some instances from heating by process of decomposition than from cold. All fresh fruit tends to generate heat by this process. A car load of fresh fruit approaching ripeness, closed up tight in an uniced refrigerator car with a temperature above 50° , will, in twenty-four hours, generate heat enough to injure it, and in two or three days to as thoroughly cook it as if it had been subjected to steam heat. Suitable refrigerator transportation must, therefore, provide for the heat generated within as well as to protect it from the outside heat. The perfection of refrigeration for fruit is not necessarily a low but a uniform temperature; a temperature from 40° to 50° will keep fruit for twenty or thirty days, if carefully handled. Strawberries have been transported from Florida to Chicago, transferred to cold storage rooms, and remained in perfect condition for four weeks after being picked.

Fruit that has been subjected to a high temperature before being shipped should be cooled immediately after being loaded. Ordinary refrigeration will not cool a load of hot fruit within twenty-four hours, and during that time it will deteriorate in quality very much. It should be cooled in four or five hours in order to prevent fermentation.

Several accounts have been published during the past two years of experiments in the use of sterilized air to prevent the decomposition of fruits, vegetables, etc. Car loads of produce have been reported shipped long distances without injury, and goods stored in sealed chambers filled with sterilized air.

The results of these experiments, however, do not seem to have been such as to lead as yet to the adoption of this system in any considerable number of instances.

Precautions taken in shipping to protect from cold are, papering, packing in straw or sawdust, boxing, barreling with paper lining, shipping in paper-lined cars, refrigerator cars, and cars heated by steam, stoves, and salamanders.

Cars containing perishable goods are sometimes, when a north wind is blowing on the prairie, covered with canvas on the north side.

In winter time refrigerator cars are used without ice in forwarding goods from the Pacific Coast, and in passing through cold belts or stretches of country the hatches are closed, and the cars being lined and with padded doors, the shipment is protected against the outside temperature; in passing through warmer climates the ventilators are opened in order to prevent the perishable goods from heating and decaying.

It is stated, however, that for the shipment of fruit the ordinary refrigerator car is not entirely satisfactory, and that there is a strong demand for a better refrigerator car than can now be obtained. A car is wanted that will carry oranges, bananas, etc., without danger of chill through the coldest climates of the country, as the delays in housing are injurious to the keeping qualities of the fruit, and the dealer is also kept out of the use of his goods.

To protect goods shipped in an ordinary car, the sides of the car should be protected by heavy paper tacked to the wall, and by the addition of an inner board wall a few inches distant from the outer one. A car thus equipped and packed with produce, surrounded by straw, will retain sufficient heat to prevent injury for twenty-four hours, the average air temperature of all parts of the car being at least 12° higher than that of the outside air. Cars are sometimes warmed by steam from the locomotive when in motion, and by stoves when steam is not available. Cars, after being loaded, are carefully inspected as to temperature within; their destination considered; and, if the weather is exceedingly cold, or is liable to be, the car is often accompanied by an attendant; otherwise it is inspected from time to time on the road. Lined cars, that is, cars lined with tongued and grooved boards on the sides and ends, are considered the best for shipping potatoes, as they can be heated by ordinary stove and will stand a temperature outside of 20° below zero, when a man is in charge to keep up the fires. The potatoes are packed in straw, bulkheaded back, center of car left empty, and car filled as high as double lining; when the temperature is 12° , or more, below freezing, the rule is to line the barrels with thick paper, and at extremely low temperatures, as a matter of extra precaution, the barrels are covered over the outside with the same kind of paper, which is considered the best known protection from frost.

Oranges shipped from Florida to points as far north as Minnesota are started in ventilator cars, which are changed at Nashville to airtight refrigerator cars, the ventilators of which are kept open, pro-

vided the temperature remains above 32°, until arrival at St. Louis, from which point the ventilators are closed and the cars made air tight.

Oranges loaded in ventilated or common cars should be transferred to refrigerator cars when the temperature reaches 20° above zero; in transit, with a falling temperature, the ventilators should be closed when the thermometer reaches 20°, and with a rising temperature the ventilators should be opened when it reaches 28°. For lemons the minimum is 35° for opening and closing the ventilators, and for bananas 45° for opening or closing. Some shippers say that ventilators on cars containing bananas, lemons, and other delicate fruits, should be closed at a temperature of 40°. In shipping car loads of bananas, a man is usually sent in charge to open and close the ventilators. Bananas should be put in paper bags inside heavy canvas bags, and then covered with salt hay, but when put in automatic heaters the fruit is packed only in salt hay.

French mustard and aqua ammonia are packed in sawdust and securely boxed, being careful to allow the sawdust to form a layer between the articles and the side of the box.

Eggs are packed in crates with separate pasteboard divisions, with a layer and a cover of oat chaff. Pickled eggs are injured by cold sooner than fresh ones.

Quinces, apples, onions, and pears are packed in barrels, each layer of barrels covered with and resting on straw.

Tomatoes, lemons, and oranges are packed in crates; each layer of crates in the car is covered by and rests upon straw, usually bulk-headed back from the door and car full.

Shrubs and fruit trees are laid on straw, covered with it on all sides, and car packed full.

Flowers are packed in moss, and car filled.

Flowers, shrubs, and trees should have their roots carefully packed in straw, and the roots placed together in two or three piles, so as to protect them; if the roots are killed they are of a uniform black; if only injured by frost the root is pinkish in color just below the outer covering, and if sound they are of uniform white. Even if of a dark pink color no damage need result, if the frost is gradually thawed out by the trees being left in the closed car for four or five days, or else the roots put well down in the soil in a horizontal position and allowed to thaw out gradually. Extra precautions are taken with trees, etc., when passing over mountains, and no shipments should be made when the temperature is likely to be zero anywhere in the higher regions.

Products sent loose in a car are packed in straw on all sides, particular attention being paid to the packing around doors, and to see that the car is full.

Manure is largely used to protect perishable goods, the bottom of

the car being thickly covered with it, and in some cases it is put on top of the goods.

The relation between the outside air temperature and the temperature within the car varies largely, depending on the kind of car, whether an ordinary freight or refrigerator car, whether lined or not, whether standing still or in motion, and also on the weather, whether windy or calm, warm or cold.

In an ordinary freight car the difference ranges from 2° to 15° , and in a refrigerator car from 15° to 30° . If the latter be provided with heating apparatus, the temperature in winter can be kept at any required degree.

From six observations taken at intervals of ten minutes it was found that on a warm day, when the mean of the six readings outside was 68° , it was 66° on the inside of an ordinary freight car, and 63° inside of an uniced refrigerator car. On a cold day the mean of six observations was 38° outside and 35° inside of an ordinary car, and 36° inside of a refrigerator car; the car was stationary.

Freight from the Pacific Coast to the Mississippi Valley, or to the Atlantic Coast, has to pass through several varieties of climate at any time of the year. It is therefore obvious that at one time the temperature inside of the car will be materially above the outside temperature, while perhaps a few hours later it will be below.

FOOD PRODUCTS IN STORAGE.

The best storage for apples and potatoes, and for vegetables generally, is a well ventilated, dry cellar, kept at a temperature between 30° and 45° . Other methods of storing potatoes in winter are: In tent-shaped houses, ventilated at the top, and covered with earth from 6 to 12 inches deep; packing in shallow pits in the ground between layers of straw or cornstalks, a layer of straw or cornstalks on top covered with earth, a hole being left in the top for ventilation; and packing in dry sand in cellars.

Apples and potatoes are also stored in specially constructed barns, made as nearly air tight as possible, fitted with crates or bins, and supplied with heating apparatus for maintaining an even temperature.

Apples keep better if, before storing, they are put in piles out of doors and allowed to sweat.

Apples are not rendered unfit for use by freezing, if allowed to thaw out gradually.

Potatoes should not be left in the sun after being dug, as the heating induces sweating and decay.

Celery is stored in an unfloored, inclosed, well-ventilated shed, the earth is well wetted, and the celery packed in an upright position, with narrow lanes about, 2 feet apart, for ventilation. The temperature should be kept as near 32° as possible; a temperature of 60° to 65° injures it.

Young fruit trees, flowering shrubs, and plants are injured by temperatures below 36° . They are stored in cellars packed in straw, and generally shipped in the same manner as potatoes as regards packing.

Where fruits, vegetables, etc., are kept in cold storage, the following temperatures are considered most favorable, viz: for apples, apricots, berries, buckwheat flour, oatmeal, corn meal, cider, cheese, cranberries, onions, dried or salted fish, furs, and woolens, 34° to 36° ; for sauerkraut, brined meats, lard, maple sirup, dried fruits, dried corn, peas, beans, etc., 40° to 44° .

Oranges on the trees will stand a temperature of 26° for an hour or so, but if exposed to that temperature for four hours will freeze inside. Oranges slightly frozen, when placed in a cool room and thawed out gradually, are sweetened, and considered by some people as improved, but when frozen solid and thawed they have a sickish sweet flavor. When oranges have been frozen they can be thawed without injury by putting them in cold water or tight barrels immediately after arrival, and allowing them to thaw out gradually.

The temperature to which lemons, oranges, and bananas may be exposed without damage depends largely on the moisture present in the air, a dry atmosphere, with either high or low temperature, being less injurious than a moist one.

Tropical fruits in storage should be kept in rooms with the temperature between 60° and 70° .

While a temperature as low as freezing (32°) will not injure potatoes for eating purposes, yet they will fail to sprout in the spring.

Wines should not be subjected to a temperature lower than 20° or higher than 72° .

Fruit wrapped in heavy brown paper will stand 15° more cold than if not wrapped.

Eastern grapes bear low temperatures better than California or Malaga.

Canned tomatoes when frozen become stringy, canned fish soft and mushy, lemons black and spotted, olives soft and rancid, pickles soft and unsalable.

Sauerkraut ferments at 90° and freezes at 15° , either of which conditions spoils it.

All tree seeds, including peach, plum, walnut, etc., sprout better in the spring if frozen during the winter. Bulbs, including tulips, lilies, and hyacinths, are not injured if subjected to a temperature below zero.

Cut flowers will keep three or four days in a temperature a little above freezing.

Fruit should be kept free from decaying matter and filth of all kinds. A spraying apparatus for cleansing choice fruit with water has been found of value. Electric fans for ventilating have been used to advantage. A free exposure to the night air, especially when

conditions are favorable for a heavy dew, is conducive to the preservation of both fruit and vegetables.

Oysters in shell can be kept for two months in a dark place when the temperature is but little above freezing if occasionally sprinkled with ice water. Fresh oysters in cans deteriorate after two weeks in any temperature unless frozen.

Fresh fish are stored and shipped in bins with cracked ice, the ice water running over them to keep them moist. Northern merchants sometimes freeze fish for storage and transportation, but they spoil more quickly after being thawed, and it is claimed that the flavor is injured by freezing. Oysters, if likely to be exposed to very low temperatures, should not be washed.

TEMPERATURES FAVORABLE FOR SLAUGHTERING CATTLE AND HOGS AND THE PRESERVATION AND CURING OF THE MEAT.

In the slaughtering of cattle and hogs, and the subsequent curing and preservation of the meat, the temperature of the air and of the dressed meats is an important factor to be considered. Opinions differ somewhat on some points as to the most favorable temperatures for these purposes, but the following are considered reliable:

Animals should never be killed while in an overheated or excited state, but should be kept quiet for twenty-four hours prior to killing, and fed lightly on cooling food. Where cold storage rooms are available in which the meat can afterwards be reduced to any required temperature, the killing may be done without injury in any weather; otherwise, a cool, dry day, with the temperature not above 45° or 50°, nor below 20°, is the most favorable. If the weather is wet or damp, the temperature should not be above 35° or 40°. The killing may be done in warmer weather than this if the temperature on the following night falls to 40°, or below. After killing, the carcasses should be hung without touching each other and allowed to remain for twenty-four hours, or more, until the animal heat has passed off and the temperature is 40°, or less, throughout. Meat thus treated may be shipped or kept for days in a temperature of 45°, or below, in dry weather; 40°, or below, in wet. When the night following the killing is warm, the hindquarters of beeves are sometimes split open to allow them to cool more rapidly. Temperatures above 50°, with moist air, damage green meats very quickly. Meat, and particularly pork, that has been frozen and afterwards thawed does not keep as well as that which has been simply chilled. Pork intended for curing should never be frozen.

It is stated that frozen meat will spoil in sixteen hours if subjected to a temperature of 75°. In the Northwestern States, where the climate is dry, the farmers, between November 15 and February 15, hang green meats in the open air, protected from the sun, and use

from them as occasion requires; meat thus kept is very tender and more palatable than that fresh killed. Meat hung up in the open air until the animal heat has passed off is said to keep better than that placed in cold storage immediately after being killed, and it is better to follow this method, if practicable, even where cold storage is available. After the animal heat is all out, the meat should be put into coolers at a temperature of 50° , and the temperature gradually lowered for forty-eight hours, until it reaches 36° , and then raised slowly to 38° . The principal injury to beef products is stated to occur from sending it from the slaughter house to the chill room before the animal heat has entirely left the carcass; this closes the pores, and the meat retains heat and turns sour. From 36° to 42° is the best temperature for storage rooms for dressed meats.

In the case of pork intended for curing, with cold storage available, it is found that a temperature which will reduce the carcass within a period of forty-eight hours to from 36° to 39° at its thickest and most vulnerable points, viz, the center of the ham and shoulder, is the most desirable. At a temperature of 40° a percentage of taint is liable to develop, and at anything over that temperature tainted meat develops rapidly. Of course, it is necessary to create an atmosphere considerably under these temperatures in order to bring down the temperature of the inside of the carcass at its thickest part to the degree mentioned, and, therefore, it is found desirable to carry the chill rooms at temperatures about 33° to 35° . It is undesirable to reduce the meat to a very low temperature, as its solid and hard condition retards the action of the salt in penetrating to the center of the piece, and thus causes the process of curing to be slower and less effective. Attaining too low temperatures has been productive of serious loss to curers, from the fact that when meat is over-chilled before the curing process begins, the cure, owing to the causes stated, has been retarded, and when exposed to the ordinary atmosphere at warm seasons the meat becomes spoiled. Some large packers place the hogs after being killed in a temperature of from 45° to 50° for twelve to fifteen hours, and then in a temperature of 35° to 40° for twenty-four to thirty-six hours. According to some experienced authorities, the carcasses should not be cut until thoroughly cooled, otherwise, the meat is apt to sour. The curing should be done in storage rooms with the temperature about 40° , the length of time for curing depending on the cut and weight of the meat, and ranging from fifteen to seventy-five days. Storage rooms cooled by the expansion of gases in tubes are considered better than those cooled by ice, on account of being drier. Dry salt pork for southern use in winter needs to be cured in salt for thirty days, but for summer use it should have from fifty to sixty days' curing. Smoked meats for southern use need to be thoroughly cured, as the heating in smoking tends to damage them.

THE USE OF THE WEATHER REPORTS IN CONNECTION WITH THE SAFE STORAGE AND SHIPMENT OF FOOD PRODUCTS.

In connection with the storage and shipment of food products liable to injury by heat or cold, much benefit may be derived from an intelligent use of the information contained in the daily weather reports and forecasts published by the Weather Bureau, which show the temperature conditions prevailing over the whole country at the time of the observations, the highest and lowest temperatures that have occurred during the past twenty-four hours, and the probable conditions that will prevail during the next twenty-four or thirty-six hours. These reports and forecasts are received at nearly every Weather Bureau office, of which there is one or more in nearly every State and Territory, and published on maps and bulletins, which are posted in conspicuous places in the city where the office is located, and mailed to surrounding towns. The reports, or a synopsis of them, are also generally published in the daily papers.

Fuller information than is obtainable from either of these sources may be had at the Weather Bureau office itself, from the observer in charge, or, where none of these means are available, arrangements may be made with the observer to supply special information by mail, telephone, or telegraph. In the large cities of the country, dealers in perishable goods are guided in their transactions very largely by the information thus obtained. The temperature of the region to which shipments are to be made is carefully watched, and the shipments expedited or delayed, according as the conditions are favorable or unfavorable. Shipments on the road are protected from injury by telegraphic instructions as to the necessary precautions to be taken. As shipments in ordinary box cars, or as freight, are less expensive than in refrigerator cars, or by express, advantage is taken of a favorable spell of weather to use the former methods.

In shipping early vegetables north from southern ports the weather reports are utilized to determine whether to use water or railroad transportation, the former being the cheaper. Dealers in certain kinds of produce, by careful attention to the daily weather reports and the weekly crop bulletins, keep themselves informed as to the sections where conditions most favorable for large crops have prevailed, and are thus enabled to judge of the probable supply and to know where to purchase to advantage.

As illustrations of the manner in which advantageous use may be made of the weather reports, suppose a merchant in Ohio has an order in January for a load of apples or potatoes to be shipped to St. Paul; when his shipment is ready he may ascertain by personal inquiry at the Weather Bureau office, or by a study of the published reports and forecasts, the probable temperature conditions between Ohio and Minnesota for the period that the shipment is

likely to be on the road, and regulate the same accordingly. If neither of these means of information is accessible to him, he may telegraph the observer at the nearest Weather Bureau office, Cincinnati, Columbus, Cleveland, Sandusky, or Toledo, as the case may be, requesting the information, or he may arrange beforehand with the observer to be informed by telegraph when the conditions are favorable for making the shipment, the cost of all telegrams, of course, to be borne by himself. While the consignment is on the road he should still keep himself informed as to the temperature conditions of the region through which it passes, and if injuriously low temperatures are likely to occur, may telegraph to have it housed or otherwise protected until the conditions are again favorable. By the use of similar means, a packer having a large number of hogs to slaughter may ascertain in advance when temperatures favorable for that purpose are likely to prevail in his locality; or a southern merchant having a consignment of tropical fruit on the road to the north may insure its protection from injuriously high or low temperatures by telegraphic instructions as to the opening or closing of ventilators, or the use of ice or artificial heat.

During the season when cold waves are liable to occur, a careful watch of the reports and forecasts will often enable dealers and others to protect from injury large quantities of produce in storage. Instances are numerous where the use of the information aforementioned has resulted in large pecuniary benefit.

During the severe cold wave of January 1 to 5, 1896, which over-spread nearly the entire United States east of the Rocky Mountains, over three and one-half million dollars worth of property was saved from destruction by the warnings of the Weather Bureau, which were sent out in advance of the wave.

The lowest and highest temperatures to which perishable goods may be subjected without injury under the conditions stated.

Perishable goods.	Lowest outside temperature.			Temperatures above which injury occurs.	Remarks.
	Articles in ordinary packages unprotected.	In ordinary freight cars.	In refrigerator or specially prepared cars.		
Apples, in bbls.....	30	10	-10	75	Covered with straw.
Apples, loose.....	23	15	-10	75	Packed in straw.
Apricots, baskets.....	35	24	-10	70	
Aqua ammonia, bbls.....	30	20	-10		
Asparagus.....	28	22		70	In boxes covered with moss.
Bananas.....	50	32		90	In bulk and in boxes with straw.
Beans, snap.....	32	26		65	In barrels or crates.
Bear.....	Zero.	-20		65	Shipped loose.
Beer or ale, kegs.....	32	20	Zero.	75	Packed in manure and shavings.
Beets.....	26	20		70	In crates.
Bluing.....	30	20	-10		
Cabbage, early or late.....	25	20	Zero.	75	Barrels or crates.
Cantaloupes.....	32	25	10	80	
Cauliflower.....	22	15		70	In barrels with straw.
Celery.....	10	Zero.		65	Packed in crates.
Cheese.....	30	25	10	75	
Cider.....	22	18	-10	70	
Clams, in shell.....	26	10	-10	65	In barrels.
Cocanuts.....	30	20	Zero.	90	In barrels or crates.
Crabs.....	10	Zero.		65	In baskets and barrels.
Cranberries.....	28	20	Zero.		
Cucumbers.....	32	20		65	In boxes with moss.
Cymlings, or squash.....	32	22		75	In crates.
Deer.....	Zero.	-20		65	Shipped loose.
Drugs (non-alcoholic).....	32	28	Zero.		
Eggs, barreled or crated.....	30	20	Zero.	80	
Endive.....	10	Zero.		70	Packed in boxes or crates.
Extracts (flavoring).....	20	15	Zero.		
Fish.....	10	Zero.		65	In barrels always iced.
Fish, canned.....	18	15	-10		
Flowers.....	35	20	-10		Packed in moss.
Grapes.....	34	20	Zero.		Packed in cork.
Grape fruit.....	32	20	Zero.		
Groceries, liquid.....	32	20	Zero.		
Ink.....	20	15	-10		
Kale.....	15	Zero.		65	Packed in boxes or crates.
Leek.....	28	20		65	Packed in boxes.
Lemons.....	32	20	10	75	In boxes or crates.
Lettuce.....	26	15		70	In crates or boxes.
Lobsters.....	25	20	Zero.		
Mandarins.....	32	20	Zero.	75	In boxes.
Medicines, patent.....	32	28	Zero.		Packed in sawdust.
Milk.....	32	28	Zero.	75	
Mucilage.....	25	15	Zero.		
Mustard, French.....	26	20	-10		
Okra.....	25	20		75	In baskets or boxes.
Olives, in bulk.....	28	25	Zero.		In barrels.
Olives, in glass.....	25	20	Zero.		
Onions, boxes.....	30	15	Zero.		
Onions.....	20	10		80	In barrels, boxes, or crates.
Oranges.....	28	20	Zero.	80	In baskets, boxes, barrels, or crates.
Oysters, in shell.....	20	10	-10	65	In barrels.
Oysters, shucked.....	30	20	Zero.	70	In barrels.
Parsley.....	32	20		75	In baskets.
Parsnips.....	32	20		70	In baskets or barrels.
Partridges.....	10	Zero.		65	In bunches in boxes.
Paste.....	32	25	10		In barrels.
Peaches, fresh, baskets.....	32	20	10	80	
Peaches, canned.....	20	15	Zero.		
Peas.....	32	20		80	In baskets or barrels.
Pickles, in bulk.....	32	18	-10		In barrels.
Pickles, in glass.....	30	16	-10		
Pineapples.....	32	25	Zero.	75	In barrels, in crates, or in bulk.
Plums.....	35	32	Zero.	75	In boxes with paper.
Potatoes, Irish.....	33	25	10	80	In barrels or baskets.
Potatoes, sweet.....	35	28	10	80	In barrels or baskets.
Radishes.....	20	15		65	In baskets.
Rice.....	30	10		90	In barrels and sacks.
Shrubs, roses, or trees.....	35	10	-10		In canvas or sacking.

The lowest and highest temperatures, etc.—Continued.

Perishable goods.	Lowest outside temperature.			Temperatures above which injury occurs.	Remarks.
	Articles in ordinary packages unprotected.	In ordinary freight cars.	In refrigerator or specially prepared cars.		
Spinach	15	15	.....	75	In barrels or crates.
Strawberries	33	25	—10	65	
Tangerines	25	15	Zero.	70	In boxes.
Tea plants	28	20	.....	95	Packed in boxes.
Thyme	20	10	.....	90	In small baskets.
Tomatoes, fresh	33	23	10	90	
Tomatoes, canned	28	25	—5	.....	In boxes.
Turnips, late	15	Zero.	.....	75	In barrels.
Vinegar, bbls	22	18	—10	.....	
Watermelons	20	10	.....	85	In barrels and in bulk.
Waters, mineral	28	25	Zero.	.....	
Wines, light	23	15	Zero.	.....	
Wild boar	Zero.	—20	.....	65	Shipped loose.
Wild turkey	Zero.	—20	.....	65	Shipped loose.
Yeast	28	25	Zero.	65	

BULLETIN No. 14.

U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

REPORT

OF THE

THIRD ANNUAL MEETING

OF THE

American Association of State Weather
Services,

COÖPERATING WITH THE WEATHER BUREAU,
U. S. DEPARTMENT OF AGRICULTURE.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., November 14, 1894.

SIR: I have the honor to request authority to have printed, in pamphlet form, 10,000 copies of the accompanying proceedings of the third annual convention of the American Association of State Weather Services, held in Brooklyn, N. Y., August 17, 1894, in conjunction with the American Association for the Advancement of Science. It is desired to distribute the pamphlets to the voluntary observers and crop correspondents, and it is believed they will prove of service in attracting attention to the weather crop work of the Bureau and result in making its value more widely known.

The Association of State Weather Services is composed largely of officials of the Weather Bureau, and was organized in 1892 with a view to increasing the usefulness of Weather Bureau work. The proceedings of the two former meetings have been published by the Bureau.

Very respectfully,

H. H. C. DUNWOODY,
Acting Chief of Bureau.

Hon. J. STERLING MORTON,
Secretary of Agriculture.



CONTENTS.

	Page.
Weather Service officials in attendance.....	7
Address of the president	8
Topics for discussion	9
Topic No. 1	10
Topic No. 2	12
Topic No. 3	14
Topic No. 4	15
Topic No. 5	17
Topic No. 6	18
Topic No. 7	21
Topic No. 8	22
Irrigation and its relation to State weather service work.....	24
Characteristics of Utah in relation to State weather service work.....	27
Letter from Mr. F. P. Chaffee	30
Officers of the association.....	31

THIRD ANNUAL CONVENTION OF THE AMERICAN ASSOCIATION OF STATE WEATHER SERVICES.

The third annual convention of the American Association of State Weather Services was held in Brooklyn, N. Y., August 17, 1894, in conjunction with the American Association for the Advancement of Science.

The call for this meeting was made June 8, 1894, by Maj. H. H. O. Dunwoody, president of the association, and a list of subjects for discussion issued July 23. While the number of States represented at the Brooklyn convention was smaller than at the two preceding conventions, the meeting was a very successful one. Had the place of meeting been more centrally located, the attendance would doubtless have been larger than at either of the preceding meetings. Notwithstanding the location of Brooklyn on the extreme eastern border of the country, one of the Pacific-Coast States and four others west of the Mississippi River had their State weather services represented at this convention. Several State weather-service directors not in attendance had expressed their intention to be present, but were prevented by circumstances beyond their control. Besides the president and secretary of the association, the following State weather-service officials were present and participated in the proceedings of the convention:

WEATHER-SERVICE OFFICIALS IN ATTENDANCE.

Mr. F. H. Clarke, director, Arkansas weather service.
Mr. T. B. Jennings, director, Kansas weather service.
Mr. Frank Burke, director, Kentucky weather service.
Mr. R. E. Kerkam, director, Louisiana weather service.
Dr. C. P. Cronk, meteorologist in charge Maryland weather service.
Dr. R. J. Hyatt, director, Mississippi weather service.
Mr. E. W. McGann, director, New Jersey weather service.
Mr. R. M. Hardinge, assistant director, New York State weather bureau.
Mr. B. S. Pague, director, Oregon weather service.
Mr. S. W. Glenn, director, South Dakota weather service.
There were also present the following named Weather Bureau officials: Messrs. E. B. Dunn, I. W. Brewer and W. L. Day, of the New York station, and Mr. John W. Smith, of the Boston station.

The president and the directors of the several services were much pleased at the presence of Prof. George C. Soun, Newark, N. J., Mr. C. L. Swain, C. E., Boonton, N. J., and Mr. John Neagle, Plainfield, N. J. These gentlemen are enthusiastic voluntary observers of the New Jersey weather service, and their attendance at and participation in the proceedings of the convention was especially gratifying to the president of the association and the several directors present. The president called the meeting to order at 10.20 a. m., and after appropriate preliminary remarks addressed the meeting as follows:

ADDRESS OF THE PRESIDENT.

At the last annual meeting of the American Association of State Weather Services, official duties enforced my absence, greatly to my regret. It is therefore with more than uncommon pleasure that I am able to be with you upon the occasion of the third annual meeting of the Association of State Weather Services.

The expansion and development of these services to a degree scarcely anticipated by the most ardent advocate of the system make it desirable, if not absolutely necessary, that those who have this important work in hand should meet in convention for the purpose of discussing ways and means of furthering their work. That former meetings have been productive of great good is amply attested by the rapid progress that has been made in the several lines of work during the two years that have passed since the establishment of this association. It is equally evident that this and future conventions will continue to produce good results. It is profitable for us to meet from time to time, to learn from discussion and personal inquiry as to the methods of work employed in the several States, that each official may return to his field of operations better prepared to prosecute and extend his work. The published proceedings of past conventions have been eagerly looked for by the State service officials not fortunate enough to attend the meetings of the association, and the valuable information that has been given through these published proceedings concerning exposure of instruments and other essentials in observation work have contributed much toward creating and increasing interest in meteorological subjects.

With about 3,000 voluntary observers taking observations of temperature and rainfall and recording miscellaneous meteorological phenomena it is possible to supply, through the State weather service, climatological information for almost any locality in the United States. Nearly every county in the whole country is now provided with a station equipped with instruments of the Government standards, and if the work of establishing new stations continues during the next two years at the same rate as during the past two years, there will not be a county within the limits of our country that will not have a meteorological station.

Since the last annual convention of State weather services, which took place in Chicago, August 21 to 25, 1893, the work of State weather-service organization has gone rapidly forward, and the past twelve months in some of the more important lines may be marked as an era of exceptional progress. While there has been a decided extension in all the branches of work conducted by these organizations, the weather-crop service and the dissemination of forecasts have received greatest attention, and in these two lines have the most marked successes been achieved.

The weather-crop service of the National bureau now undoubtedly ranks next in importance to the work of making forecasts. The system of gathering reports upon which the weather crop bulletins are based has been so perfected in recent years that further improvement in some States can scarcely be expected. The crop bulletins of the States have been improved and are now more complete than at any previous time, and the increased circulation that these bulletins has attained amply

attests their value. It is believed that there is no other class of information to which so much space is devoted in the public press to-day. A file of these bulletins for all the States for a year will form a most complete history of the weather conditions attending the growth and development of the several crops throughout the country.

More than 10,000 crop correspondents are to-day coöperating with the national weather service through the State organizations, 3,000 voluntary observers are furnishing monthly reports of daily observations of temperature and rainfall, and over 11,000 persons assist in the work of distributing the weather forecasts of the national weather service. This latter work has been more rapidly pushed during the past year than any other feature of State weather-service work, and it is expected that during the ensuing year the already large number of communities receiving the Government weather forecasts will be further increased from 5,000 to 6,000. With a continuation of the present liberal policy of the Honorable Secretary of Agriculture and the Chief of the Weather Bureau toward these services, there will be in a comparatively short time no important agricultural community in the United States, with the proper mail facilities, that will not receive the benefits of the forecasts.

The monthly reports of many of the States are model publications of their kind. It is to be hoped that in those States where as yet the more approved methods of publishing meteorological data are not practiced, means may be found by which their reports may be improved and raised to the standard attained where better facilities have been available. Uniformity in size, as far as practicable, and strict uniformity as to tabular data are very desirable. A daily record of temperature and rainfall for purpose of detailed investigation is most essential, and these should, if possible, form a part of each report.

It is believed that nothing can contribute more toward securing reliable and accurate observations than an inspection of the voluntary stations, that the observers may be made thoroughly acquainted with the proper conditions of instrumental exposure and be informed as to other essentials connected with their work.

It is to be hoped that at future meetings there will be not only a large representation of State weather service officials, but that many voluntary observers, crop correspondents, and displaymen may be present.

After correspondence and personally consulting with officials of the American Association of State Weather Services, a programme of subjects for discussion at this meeting has been formulated and published. No doubt other important matters not therein enumerated will be suggested by members present and will receive your careful consideration.

Having originally suggested the organization of State weather services, and having watched with keen interest their rapid growth for more than a decade of years, I shall not in the future lose that interest I have always taken in their operations, believing that the State weather service affords the most effective means of reaching the masses of people with information collected by the National Weather Service. I will conclude my remarks by expressing to the members of the association my thanks for the honor they have twice conferred by electing me their president.

TOPICS FOR DISCUSSION.

Topics for discussion at the third annual convention of the American Association of State Weather Services are the following:

1. Crops, in relation to normal or abnormal conditions of temperature and rainfall during the periods of growth and development. Can not State weather services collect and utilize statistics as to the conditions of rainfall and temperature under which full, average, or short yield of the various crops are produced?

2. Day of issue of the National and State weather crop bulletins. What can be done to increase the value of these publications?

3. Would it not be of advantage to each State weather service center to have actual (not interpolated) daily normals of temperature and rainfall for all weather bureau stations within its territory?

4. Is Form No. 1053 Meteorological the best that can be adopted for the reports of weather crop correspondents? Should Form No. 1067 Meteorological provide for an expression of opinion by displaymen as to the verification of forecasts?

5. Monthly publications of State weather services:

(a) Should the publication of monthly reports containing advertisements be encouraged?

(b) Publication of daily temperatures and precipitation—are data published in this form used sufficiently to justify continuance of their publication? Could the cost of same be expended to better advantage for permanent detailed records for each station, to be filed at the central station, where all requests for data might be met?

(c) Is it not important that, as far as practicable, uniform methods of graphic illustrations of meteorological conditions be adopted?

6. Dissemination of weather forecasts:

(a) Distribution of forecasts through the mails by logotype system.

(b) Are not the objections to the present plan of telegraphing to flag display and whistle signal stations forecasts of decided weather changes only, such as to justify the increased expense of returning to the former system of daily telegrams?

(c) Should the present system of flag displays be continued?

(d) Could a night signal be employed to advantage, and can the system of sound signals be extended?

7. Inspection of voluntary stations.

8. What should constitute the instrumental outfit of a voluntary meteorological station?

After the address by the president of the association, the several subjects were discussed in the order proposed in the programme.

TOPIC No. 1.

Major DUNWOODY. I have given much attention to this subject in recent years, having prepared a number of charts giving for each State the actual rainfall, temperature, cloudiness, and humidity determined from the records of the Weather Bureau. Of course, these charts were necessarily more or less incomplete, owing to lack of data. They covered ten years and gave monthly averages, with departures from normal, represented graphically, so that the eye could readily discern the regions of excess or deficiency. In the same manner the departures from the average yield of the several crops were given, the regions where more or less than the average yield being illustrated by colors. By these charts the character of the yields and the meteorological conditions under which the crops were produced can be compared and studied. In the preparation of the charts referred to, a great difficulty was experienced from the unsatisfactory character of the data obtainable as to yields of many of the crops grown, but as to corn and some other staples it was possible to determine the conditions that it was desired to illustrate.

It is thought that more satisfactory conclusions might be deduced if, instead of attempting to give these data for the whole country, a single county were taken. For example, the State of Illinois, with more than one hundred counties, has but three weather bureau stations actually within its limits. The meteorological data for these stations are totally inadequate for the purpose in view. It is therefore

believed that the subject might be much more satisfactorily investigated by taking the county in which the Weather Bureau station is located and making the comparisons. I am trying to introduce this system so that thereby it may be possible to make some forecast as to yield. It is now a great question with this country as to the yield of the corn crop of the present year, owing to the prevalence of the recent hot winds over some of the principal corn States of the northwest. This is a great problem, and if we can accomplish its solution it will be of great help to the farmers of the country by giving them the most impartial information obtainable as to actual yields, and this was the idea I had in view in including the matter in the list of subjects for discussion at this convention.

Mr. PAGUE (Oregon). This is a line of work that will lead to a more thorough study of climatic conditions and crop productions. At the present time we have no authentic, rather no thorough, census of crop productions from year to year. Provision should be made to collect crop statistics as thoroughly as we collect climatic data, and not until then can reliable work be done in this direction. Many years ago I endeavored to deduce the relation that existed between the rainfall and wheat production in California, but owing to lack of data the study could not be made as thorough as was desired. Sufficient was deduced to show that the cereal crop of California depended more upon the rainfall of April and May than upon any other factor and that the increased rainfall in these months made increased total production. In Oregon we have no crop statistics, except those in census years. The lack of such important data seriously retards the practical application of data in hand to the future crop products. The prosperity of our nation depends upon the success of the agricultural classes, and the valuable crop forecasts that could be issued on the data that should be extant would be appreciated by all classes of people and by none more so than the farmers.

Mr. JENNINGS (Kansas). I consider this subject one of vital importance to the agriculturists of the country. From investigation of records in Kansas covering twenty-five to forty years I have found that every seven years that country is subjected to drought. According to this theory I believed that the season of 1894 would be one of deficient moisture, and at the beginning thereof advised farmers to plow their "trash" under instead of burning it, as is the general custom. This had the effect of retaining the moisture in the ground, and notwithstanding the marked deficiency in rainfall in Kansas up to last Saturday (August 11), corn was in good condition. Last Saturday the temperature rose to 104°, and this high temperature, with the effects of the protracted drought, had the effect of whitening the blades, but did not materially injure the grain, while in those sections where farmers either had not the advantage of the director's advice or failed to heed it, the prospects for corn are less favorable. From the

study of the records I was satisfied that there would be a deficiency in rainfall during the crop season of 1894, and those who heeded my advice as to plowing under the "trash," rather than burning it, did so to their profit.

TOPIC No. 2.

Mr. TOWNSEND (Pennsylvania). If the daily papers are relied upon as the principal means of dissemination of crop information there can be but little difference either for or against any day, but if the weekly paper affords the best means of dissemination, then Tuesday is the best day on which to issue the bulletin. In Pennsylvania beyond doubt Tuesday is the best day upon which to publish the bulletin. I think, however, that if the bulletins are issued once in two weeks all interests will be as well served as under the present system.

Mr. MCGANN (New Jersey). The day of issue of the weather crop bulletin is of vast moment to the respective State weather services, and should be so fixed as to secure its publication in the largest possible number of weekly papers. Since the change from Saturday to Tuesday was made I have found that some weekly papers have been unable to use the information, but upon the whole I agree with Mr. Townsend that it is best to publish the bulletin on Tuesday. The edition of New Jersey weather bulletin is 2,200 copies; it is received from the printer at 2 p. m. and by 4 p. m. the whole edition is in the mails. The plan of publishing notes from correspondents is, in my opinion, the best that could be adopted, as readers of the bulletin like to be informed as to the correspondent furnishing the report; besides, it is a source of compensation to the correspondent to have due credit given him publicly for his report. I believe that other State services should make this plan of giving the correspondent's notes and publishing their names a prominent feature, as is being done in New Jersey. [Mr McGann here cited several instances where the information contained in State bulletins had been used to the pecuniary advantage of the farmer, and also read from communications received from the director of the New Jersey Agricultural Experiment Station attesting the value of the State weather service, especially the weather crop feature.]

Mr. KERKAM (Louisiana). In Louisiana the daily papers have given such extensive circulation to the crop bulletin as to make its circulation in the weekly papers of minor importance. I have, however, found that nearly all weekly papers in the State can get the bulletin as published on Tuesday in time for publication. I favor the use of the millio-graph in furnishing the press with copies of the bulletin for publication, as by this means it can be more promptly issued and is more readily accepted as news matter by newspapers which, as a rule, care little for matter that has been put into type outside their own offices.

Major DUNWOODY. Even though the bulletin should be printed at every central station, a special summary might be prepared for the press, covering the more important features of the weather crop conditions of the week.

Mr. BERRY. The question of the day of issue of the National and State bulletins is one that has received careful consideration on the part of the Chief of the Weather Bureau, who, after thoroughly looking into the matter and weighing the various interests concerned, has decided that Tuesday, upon the whole, is the best day on which to issue them. It is true, however, that there are some very important agricultural journals that will not publish the bulletins; but this will be the case, no matter on what day the bulletin might be published. It is my opinion that Tuesday is the day on which the bulletin should be continued to be issued in order to give the public the greatest possible benefit.

Mr. JENNINGS (Kansas). The Kellogg Newspaper Company, of Kansas City, prints the Kansas crop bulletin in 500 "patent" sheet papers supplied by them; no other day will suit so well for this work in Kansas as Tuesday. The reports from weather crop correspondents, which begin to arrive Monday, are closely scanned and the special features charted on maps that they may be more easily summarized and discussed. As to improving the character of the State bulletin, the publication of remarks of correspondents is no doubt the best plan, but it is not practicable at present in Kansas, as no means of printing are available. Files of the printed bulletins of other States are being collected to show their superiority over the milliograph, with a view to procuring means of printing. Five to eight stencils are necessary for a single issue.

Mr. TOWNSEND (Pennsylvania). It is very important that all State bulletins should be issued at the same time, but the interval between the issues might be lengthened. This would avoid the repetition of much that is now told over and over in the weekly issues.

Mr. PAGUE (Oregon). I do not favor increasing the interval between the issues. In Oregon hot winds sometimes prevail which in a very short time have most decided effect upon the crop outlook. In western Oregon the crops never fail, but in eastern Oregon the hot winds that are liable to occur sometimes reduce excellent wheat prospects to such condition that in sections its only value is that of straw. The printing of notes from crop correspondents is a good plan, but it is impracticable to print them in full in each issue. A good plan is to select certain reports for publication one week and others the next, going through the whole list during the season. The crop telegram to Washington Monday night is filed and summaries given to Associated Press and to newspapers, but it is not generally published by the press until Tuesday. By distributing judiciously to the different points, it is arranged so as to reach all papers at about the same time, by mailing to the more distant points first. The bulletins should be made so brief as not to tax the space of newspapers.

Mr. GLENN (South Dakota). In South Dakota a brief summary is preferred to a more detailed report. It is impracticable to give notes

from correspondents, there being from some counties as many as twenty-five, when special requests for information are sent to postmasters. Tuesday seems to be the best day on which to issue the bulletin.

Dr. CRONK (Maryland). Though at first favoring the issue of the bulletin later in the week, I now believe the best results follow the issue on Tuesday. Not many farmers take the daily papers, and the weeklies reach a larger number, and it is through the weekly papers that the Maryland bulletins attain greatest circulation. Our bulletin is proofed by noon and mailed by 2.30 p. m. Tuesday.

Mr. HARDINGE (New York). While a majority of the papers in New York are in favor of the issue on Tuesday, they are those of minor importance; the papers with largest circulation prefer Saturday.

Dr. HYATT (Mississippi). Tuesday is without doubt the best day on which to publish the crop bulletin in our State.

Professor SONN (Volunteer Observer). There is a surprising lack of information as to existence of the weather-crop service. If the bulletins were displayed in post-offices the system would become more generally known and prove of greater benefit.

Mr. JENNINGS (Kansas). For the last three years the Kansas bulletin has been placed in at least one post-office in every county, and in some counties in several post-offices. The demand for the Kansas bulletin is such that individuals other than correspondents are not supplied, but the bulletins are displayed in prominent places for the benefit of the public.

Major Dunwoody commended the plan of displaying the bulletin in post-offices. A recent act of Congress provides for more intimate cooperation between the Weather Bureau and the Post-Office Department, and no doubt since the issue of the recent letter of the Postmaster-General concerning the distribution of storm warnings more attention will be paid to the distribution of information emanating from the Bureau.

Mr. MCGANN (New Jersey). Good evidence is available of the value of displaying the bulletins in post-offices, and I commend the plan.

Mr. GLENN (South Dakota). The "patent-sheet" newspapers afford excellent means of publishing weather crop information.

Dr. CRONK (Maryland). Bulletins printed on both sides are unsatisfactory for purposes of display.

Mr. MCGANN (New Jersey). In reply to objection of displaying bulletins printed on both sides, I would say this difficulty is met by posting two copies.

TOPIC No. 3.

Mr. KERKAM (Louisiana). I use nothing but actual daily rainfall normals for each day in the year and have computed such normals for every station in the State having records of sufficient length. These normals are bound in book form for convenient reference, from which the dry and rainy periods may be readily seen. The rainfall in Louisi-

ana varies largely, being very heavy in the southern portion, but the northern part of the State is subjected to periods of dry weather. I find these normals of great value in the preparation of frost predictions. [He cited an instance where a study of the average minimum temperature prompted the issue of frost warnings that were verified and that proved of great value.]

Mr. MCGANN (New Jersey). The rainfall normals computed from the records of the New Jersey weather service are of the greatest importance. Some scientists have predicted that portions of New Jersey would become a desert, basing their calculations upon measurements of rainfall of questionable accuracy. I have prepared these normals for decades, and published statements showing how many decades during the periods covered by the records have excessive or deficient rainfall. These data have been used to excellent advantage by engineers in constructing reservoirs. Had the State weather service been prepared to give this information five or six years ago the city of Newark would have saved hundreds of thousands of dollars in its public works.

TOPIC No. 4.

Mr. BURKE (Kentucky) presented a communication from Mr. H. L. Ball, his assistant at Louisville, recommending the use of a return postal card in the collection of weather crop reports, the object being to secure greater regularity in the receipt of reports.

Mr. TOWNSEND (Pennsylvania). The crop correspondents of the Pennsylvania service report with sufficient regularity to provide all data necessary for the weather crop bulletin. I do not believe that any change in the present style of Form No. 1053, Meteorological is advisable.

Mr. MCGANN (New Jersey). While the present card, Form No. 1053, is satisfactory, the paper should be of better quality.

Mr. JENNINGS (Kansas). Form No. 1053, at present in use, is well suited for the purpose intended, and I do not believe that such a card as suggested by Mr. Ball will prove satisfactory. The quality of paper is inferior, and the card is too wide to pass through the mails without injury. Postmasters should be instructed not to stamp these reports on the side intended for the report, as the postmarks often render the matter reported illegible. As to providing on Form No. 1067 for an expression of opinion from displaymen as to the verification of forecasts, the plan is not satisfactory. Displaymen have been known to report 100 per cent verification for five or six months when such a percentage could not possibly be attained, while others have reported complete failure, when no doubt the forecasts were highly satisfactory. I do not believe that the estimates given are of practical value.

Mr. PAGUE (Oregon). It is of interest to have displaymen note the verification or nonverification of the forecasts and I suggest that where the estimated percentages are unusually high or low, such cases should

be investigated and the reasons ascertained for such estimates. I am inclined to think well of the return postal card for the collection of crop reports, as suggested by Mr. Ball, but am in some doubt as to whether it would prove satisfactory. The present style of Form No. 1053 is admirable. The Form No. 1067, Meteorological, used by displaymen, should provide for verification estimates.

Mr. TOWNSEND (Pennsylvania). It will be well to have the card Form No. 1067 provide for such statements as "Good," "Fair," "Bad," but it is not advisable to attempt to give percentages.

Mr. KERKAM (Louisiana). The reports of voluntary observers may be used in determining the accuracy of verifications as given by displaymen. If the latter are kindly requested to note verifications they would comply.

Dr. CRONK (Maryland). The present Form No. 1053 is satisfactory.

Mr. GLENN (South Dakota). The crop report form is too wide for convenient handling in the mails, the forms being frequently broken on the edges. It is important that correspondents sign their reports. I have adopted the plan of thanking correspondents for reports of exceptional worth, notifying them by postal card when reports are received too late for current work, and call upon delinquents to resume reporting. Additional duties should not be imposed upon forecast displaymen, and therefore I do not favor requesting them to give percentages of verification.

Mr. JENNINGS (Kansas). I do not call upon delinquent crop correspondents to resume reporting, but drop their names from the mailing list for the bulletin. When the bulletins are discontinued they quickly ask that their names be restored to the mailing list, and I advise them that the conditions upon which the bulletins can be had is, that they contribute reports, and they usually comply.

Mr. PAGUE (Oregon). In order to insure identification of reports, in case of failure to sign, the name of the county is stamped on each card form before distribution. This enables me to determine in nearly every instance who the reporter is, or at least the county from whence the card came, in case of failure to sign.

Mr. HARDINGE (New York). I favor the present Form No. 1053, except as to quality of paper, which should be better. I do not favor providing a column for percentages of verification on Form No. 1067.

Dr. HYATT (Mississippi). It is advisable to have displaymen give estimates as to verification of forecasts.

Professor SONN, voluntary observer and display man at Newark, N.J., made some excellent remarks relative to the duties and cooperation of voluntary observers and displaymen, stating that it was his custom to keep record of both forecast and the weather conditions following, in order that he might be able to answer criticism. Professor Sonn's remarks as to the exactions on the part of the public, with reference to the fulfillment of the forecasts, were both amusing and interesting, and

evinced a keen interest on his part in the work of the Weather Bureau. He found numerous instances of unfair criticism of the Weather Bureau's forecasts, especially with reference to local rains in summer, stating that many people would not admit that such forecasts were justified unless it actually rained upon their hats. At the conclusion of Professor Sonn's interesting remarks he was personally thanked by the president in behalf of the association. This concluded the morning session (1 p. m.), and a recess was taken until 2 p. m., when the work of the convention was resumed.

TOPIC No. 5.

Mr. BURKE (Kentucky). I am opposed to the plan of publishing monthly reports of State weather services containing advertisements upon which the support of the publication is to be derived. The time required for soliciting advertisements and keeping proper account of the receipts and expenditures can be illy spared by the officials in charge. Such enterprises are usually conducted at personal sacrifice, having myself lost \$50 on the first attempt to publish the report of the Kentucky service by this plan. I find that opposition on the part of the agricultural press is engendered by such undertaking, one editor having stated that he considered it undignified on the part of Government officials to solicit patronage for such a publication. Soliciting advertisements and subscriptions tends to impair the official standing of the representative of the Bureau.

Mr. CLARKE (Arkansas). I have tried the experiment of raising funds by advertisements and subscriptions, but without success, owing to the depressed financial conditions prevailing. I agree with Mr. Burke that there are features of this plan decidedly objectionable, as lowering the standing of the Bureau's officials.

Mr. PAGUE (Oregon). I recognize the objectionable features referred to by Messrs. Burke and Clarke; still, I believe that such means are justifiable where no provision for publication is made by the State. Although the Oregon report is now published at the expense of the State, it was published at one time by an arrangement somewhat similar to the plan referred to as objectionable.

Major DUNWOODY agreed substantially with Mr. Pague as to the plan of publishing reports in those States where no support had been provided.

Mr. CLARKE (Arkansas). With reference to the question of publication of daily temperature readings and measurements of rainfall, I think that the National Bureau might supply record books for these data. I also favor graphic illustrations in presenting the meteorological data wherever practicable.

Mr. PAGUE (Oregon) enumerated the great advantage of presenting meteorological conditions in graphic form. The excellent charts accom-

panying the reports of the New York meteorological service made him envious, and he had endeavored to adopt a similar plan in Oregon.

Upon inquiry by Mr. McGann (New Jersey), Mr. Hardinge (New York) stated that the cost of each edition (about 800) of the New York report cost \$28.50. The question of cost of meteorological charts was discussed, and it was found that the expense for creditable charts was greater than most of the State services could bear.

As to shading of rain charts, Mr. Berry favored the adoption of the scale of shades used in the Monthly Weather Review. By this scale the shading increases with the amount of rainfall reported, so that the region of heavy and light precipitation may be seen at a glance.

TOPIC No. 6.

At the request of the president, a sample logotype printing outfit, such as is used in printing the forecast messages, was exhibited by Mr. Berry, and its use was explained to those not already familiar with the system.

Mr. MCGANN (New Jersey). It is desirable to lengthen, if possible, the period covered by the forecasts. If the forecasts could be made for forty-eight hours it would be possible to reach by mail a largely increased number of places that it is now impossible to serve until so much of the time covered by the forecast has lapsed that the information proves of little value.

Mr. TOWNSEND (Pennsylvania). I agree with Mr. McGann as to the necessity of predictions of long range and believe that such forecasts might be made by the officials of the Weather Bureau, who are in position to know better than the public what weather conditions might reasonably be expected to prevail forty-eight hours in advance. The percentage of verification that might result from lengthening the period would be more than compensated for by the value of the successful predictions.

Mr. CLARKE (Arkansas). There are but few points in my State that do not receive the thirty-six-hour forecasts made in the morning almost as soon as issued, and the stations receiving them latest have at least thirty hours of the period unexpired by time of receipt.

Major DUNWOODY. To extend the period covered by the forecasts beyond thirty-six hours would, as a rule, render the predictions mere guesswork.

Mr. TOWNSEND said there was a disposition on the part of the press to publish long-range forecasts, such as published in the New York Herald.

Major DUNWOODY stated that he believed that interest in such forecasts would die out.

Mr. TOWNSEND thought that it would be well for the Bureau to take the matter of long-range forecasts under consideration.

The logotype system for the distribution of forecasts by mail was considered by all State-service officials present to be the most economical and effective plan that has yet been tried for the dissemination of weather information. With reference to the present plan of telegraphing the forecasts only when decided precipitation or decided temperature changes are expected, it was the opinion of all present that the system was objectionable and that the Bureau should return to the former plan of sending the forecasts daily.

Mr. TOWNSEND said that it was difficult to make the public understand the conditions upon which the forecasts are sent, and that messages should be sent daily. Messrs. McGann, Hardinge, Cronk, Hyatt, Pague, and Smith (local forecast official, Boston) agreed with Mr. Townsend that the messages should be sent daily.

Mr. JENNINGS. In Kansas the present plan receives no praise and much unfavorable criticism. The only thing in its favor is its economical feature, but the loss to the Bureau for less efficient service is great. The plan necessitates much explanation, and the unfavorable criticisms can only be successfully met by the statement that the Government by this plan can supply a greater number of places with the forecasts than would be possible otherwise.

Among other objections to the present plan, Mr. Clarke referred to the gradual rises in temperature from day to day, by which marked extremes might occur with no forecasts from the Weather Bureau.

Mr. GLENN. The infrequency of the telegrams cause displaymen to be indifferent in making the displays and rendering correct monthly reports. An objection to the plan is the uncertainty to which specially interested persons are subjected by the absence of a telegram indicating fair weather and stationary temperature, when very important and valuable weather information can be long delayed in transmission by broken, crossed, or grounded wires, an open key, or the indifference of an operator, and the occasion of the delay not be known to the general public. In South Dakota it was of the greatest importance that daily forecasts should be telegraphed, as lack of such information in winter might sometimes result in loss of life.

Messrs. Townsend, Hardinge, and Jennings spoke of delays in delivering messages resulting from unsatisfactory telegraphic service, Mr. Hardinge stating that investigation of such delays had always resulted in improved service. With reference to the question whether the present system of flag signals should be continued, while Messrs. Townsend and McGann were of the opinion that the objections to flags were such as to justify their discontinuance, Messrs. Hyatt, Clarke, Glenn, Hardinge, Jennings, and Berry were in favor of continuing the flag system. Mr. McGann stated that he found that displaymen were inclined to neglect changing the flags and that the bad effects of having flags flying that did not represent the official forecasts were such as to persuade him that flag displays should be abandoned and the logotype system extended.

Mr. BURKE was also of the opinion that the logotype bulletins afforded a more satisfactory means of dissemination.

Mr. GLENN. The flag system is satisfactory in South Dakota, but a flag might be designed that would serve to indicate both temperature and weather in a single display, doing away with the present temperature flag. The scarcity of lumber renders the securing of a good flag-staff difficult and expensive, and as buildings are generally low, the size of the flag might be reduced with advantage.

Mr. PAGUE. I would dislike very much to see the flag system dispensed with. The system is popular throughout the Pacific Coast and especially in the raisin districts of California. The logotype plan is good, but it fails to serve purposes that are fully met by the flags.

Mr. CLARKE. The flags have so long successfully been employed by the Weather Bureau as a means of communicating information that I hope that their use will be continued.

Mr. BERRY. I favor flags, and while admitting that the system is defective, it possesses many merits, and I believe that it could not be dispensed with without impairing the usefulness of the Bureau. The flags should be continued and the logotype system extended. With both these popular means of dissemination the Bureau can do a great deal more than with either alone.

Mr. MCGANN. The definitions of the flags are not generally known and people will not take the pains to inform themselves as to their meaning, but with the logotype bulletin each person can read the message, and this is more satisfactory.

Mr. GLENN. Some of the most zealous displaymen in South Dakota are sometimes remiss in the matter of rendering reports of displays; and the enforcement of the rule requiring the cutting off of telegraphic service unless reports of displays were rendered, in some instances, resulted in the loss of their cooperation, much to my regret. I am in favor of allowing the telegrams for the purpose of bulletin displays where flag displaymen are not available, except in the larger towns.

Mr. MCGANN. It is my experience in New Jersey that it is not a desirable plan to have one person act in the capacity of voluntary observer, displayman, and crop correspondent, and I advise that different persons be secured to act in the several capacities.

Referring to night signals, Mr. Townsend said that the short distance which these signals could be seen would render such system faulty; the proper appliances would prove too expensive to render such a plan feasible.

Mr. Jennings also thought that the expense of night signals would be too great to make any system that might be tried practicable.

Mr. GLENN. I regard the question of long-distance signals as one of much importance to the Weather Bureau. On the plains the light from extensive prairie fires can be seen a distance of about 90 miles, and if some effective means of communicating forecasts by means of night

signals can be devised it would doubtless prove of great benefit in my State. I have given considerable thought to this question, considering the use of bombs, rockets, etc., and think that it would be well for the National Bureau to conduct some experiments in this line. The Weather Bureau observer at Pierre, S. Dak., is very favorably situated for testing any such system.

Mr. JENNINGS. So far as distance at which the lights might be seen is concerned, electric lights may be seen 20 to 25 miles distant from an observer, and objects may be seen in daytime 30 or 35 miles away, so that there can be no doubt, if proper appliances could be had at an expense that would not be too great, such signals would be the means of making known the forecasts over a wide extent of territory.

Major DUNWOODY. From experiments made in Pennsylvania, at Williams Grove and Mechanicsburg, with lights and rockets, the farmers were favorably impressed with the system. The Weather Bureau officials at Pierre or Huron might be able to do effective work in the way of announcing cold waves.

Mr. GLENN. In my opinion long-distance night signals should be used only for cold wave and storm warnings, and not for the ordinary daily forecasts.

Mr. PAGUE. There are instances where the forecasts had been displayed by stereopticon lights on the stages of theaters with good effect, and I believe the plan to be very good. Of course such a system could only be used in the populous cities. Experiments had been made with flash lights between Mount Hood and Portland, Oreg., a distance of 70 miles, but the light was of insufficient power to prove effective. If a plan of night signals could be put into successful operation at Mount Hood it would give 150,000 people the benefit of the forecasts. On account of the difference between Pacific Coast and Eastern time it is possible to give the forecasts based upon the 8 p. m. (75th meridian time) observations distribution on the Pacific Coast at an hour sufficiently early to make the forecasts of much greater value than would be possible if distributed two or three hours later (local time), as is the case east of the Mississippi River.

TOPIC No. 7.

Mr. CLARKE. I have spoken at farmers' conventions of the great need for the inspection of voluntary stations, and long recognized that such inspections are of the first importance; and after having succeeded in providing the necessary means, the general authority was cut off by the central office of the National Bureau, so that the trips could not be made without a specially granted authority for the necessary absence in each case. [As evidence of the necessity for the inspections, Mr. Clarke cited cases in which it had been found that the maximum thermometers in use were acting as ordinary exposed thermometers, thereby giving erroneous records.] Until the officials were given the

general authority that they formerly had, these inspections could not be advantageously made.

Mr. MCGANN. It is of the utmost importance that inspections be made, and it will not only be necessary to restore the former general authority for the necessary absences, but the time should be extended to cover three days; the former authority allowed two days. It is a pleasant duty to meet the voluntary observers of the State service, who are among the best classes of people, and acquaint them in their work.

Mr. JENNINGS. A personal inspection of voluntary stations brings the directors and observers nearer together and arouses greater interest in the work. I find that observers welcome the visits of the director for the purpose of inspection. There being very few instrument shelters in use in Kansas, inspections become the more important, that the best exposures possible without shelters may be secured. [He cited a case where the readings of the minimum thermometer were made at the wrong end of the index.] Such errors are liable to occur with persons who under proper instruction from personal inspection become the most efficient observers. Months of correspondence often fails to accomplish what can readily be effected by personal interview.

Mr. GLENN. I agree with Mr. Jennings in what he said with reference to inspections. In South Dakota some of the most indifferent observers have, as a result of personal instruction, become the most efficient. Owing to distances and difficulties in travel, the time limit for inspections should be increased to four days.

Mr. TOWNSEND. It is of the utmost importance that voluntary observation stations be inspected for the purpose of remedying defects in instruments. Air specks in thermometers prove troublesome and are easily removed by an experienced person, but many instruments are broken by inexperienced persons in their efforts to correct such defects. I found in one case a maximum thermometer suspended after the manner of the ordinary exposed thermometer.

Mr. PAGUE. I have at former conventions urged the importance of inspecting voluntary stations for the purpose of forming the acquaintance of observers and giving them instruction. These inspections bring the collaborators in State service into close, harmonious relations, and, to secure best results, should be made annually. An annual inspection of stations will do more to develop our work than any other means can possibly accomplish.

TOPIC No. 8.

Mr. JENNINGS. The present outfit, consisting of a set of maximum and minimum thermometers and a rain gauge, is satisfactory. A more extensive outfit would be inadvisable, at least at the present time, in view of the difficulties met in securing the best results possible with the present outfit.

Dr. CRONK. The outfit mentioned by Mr. Jennings is ample.

Mr. TOWNSEND. Efforts to secure humidity observations in Pennsylvania have been unsuccessful, and nothing other than a suitable instrument shelter should be added to the observer's present equipment, viz, maximum and minimum thermometers and rain gauge.

Mr. MCGANN. I consider wind vanes as necessary, and I shall endeavor to provide New Jersey observers with them.

Mr. Townsend asked an expression as to the hours of observation.

Mr. Jennings stated the Kansas observers were requested to take their observations at 7 p. m. "railroad time," corresponding to the 8 p. m. 75th-meridian time.

Mr. Hardinge stated that the New York observers were instructed to take their observations about sunset, no more definite hour being fixed.

There being no further remarks, and the programme of subjects having been gone through with, the president stated that he would be pleased to have the directors present relate their experiences with reference to efforts made to secure State or local aid in carrying on the work of their respective services.

Mr. TOWNSEND. Pennsylvania has appropriated \$6,000 for the work of the weather service in that State. This sum is used in the purchase of instruments for observers, printing the reports, and employment of an assistant. Several years ago the State had made an appropriation of \$5,000, then there was an interval when no support was furnished. The disbursements are made by the secretary of internal affairs. The meteorological committee of the Franklin Institute has charge of the service, and under them the assistant director carries on the work. The local service is well and popularly known throughout the State. The crop bulletins are printed; and as the widest circulation of the information they contain is to be had through the press, my efforts are mainly in that direction rather than by individual distribution.

Mr. HARDINGE. The New York State weather bureau is now under the State department of agriculture. An appropriation of \$4,500 for its support was made, the disbursements being under the State commissioner. The work of the State service is steadily increasing.

Mr. GLENN. The first session of the South Dakota legislature passed a bill creating a State weather bureau, but the appropriation requested for its support (\$600) failed of passage. A similar measure failed of passage at the second session on account of the large appropriations made in connection with the State's exhibit at the World's Fair. At present I can not look for State aid. The crop bulletin is a popular feature of the work in South Dakota.

Dr. HYATT. No bill has yet been passed for the support of the Mississippi service. The service is very popular and the excellent work that has been accomplished this year, with the abundant crops, should be favorable to the proposition for State aid.

Mr. MCGANN. The New Jersey service was organized some years ago and an appropriation of \$1,000 per annum made for its expenses. For

several years I met with defeat in my efforts to secure assistance, but after severing all relations with colleges and scientific institutions, and promising that the State service should be made of practical value, an appropriation of \$1,000 was made by the State. In addition, the State board of agriculture provides \$100. Within the \$1,100 the expenses of the service are confined.

Mr. JENNINGS. Owing to complicated political conditions existing in Kansas, no State aid has been secured, and the local service relies entirely upon the National Bureau, and with the support received is able to accomplish valuable work. Monthly meteorological reports are issued by the milligraph process, but the State board of agriculture publishes the report in printed form quarterly. The railroads make extensive use of the meteorological data in publishing among immigrants the climatic features of the State.

Dr. Cronk explained the conditions under which the service in Maryland is operated. The legislature having provided an annual appropriation of \$2,000 for its support, the Governor would not approve the act without assurance that but one-half the sum appropriated would be expended. After the service had been in operation one year, however, he withdrew his restriction and permitted the whole sum to be used.

Mr. PAGUE (Oregon). The Oregon service was organized by myself in 1886, the first monthly reports appearing in the Commercial News, published in the city of Portland, during the autumn of 1887; in 1888 a paper was started which was devoted entirely to the work of the service. Through circumstances the work was discontinued with the August, 1888, issue. The Oregon legislature, at its session in February, 1889, passed a bill creating the State weather service and making an appropriation of \$2,000 for the same. By a constitutional provision the State printer is required to print all reports, blanks, etc., for State officers, hence the printing for the service does not come out of the appropriation. At subsequent meetings of the legislature aid has been continued to the service. The service is well known and popular in the State. The people rely upon it for climatic, crop, and other statistics. The press of the State recognize its value and importance. I am proud of the Oregon service, a creature of my own making; a valuable adjunct to our National Bureau; a much prized, respected, and useful organization to the people of my State. We have the cordial support of all colleges and scientific associations, the farmers' organizations, the good will and assistance of the business and public men of the State.

The following papers submitted by absent directors were presented and read:

IRRIGATION AND ITS RELATION TO STATE WEATHER SERVICE WORK.

In this crop season, when in the great central States of the Mississippi Valley long-continued and unexampled droughts have parched and ruined once promising crops; when stock has died for lack of water; when destruction has been wide-

spread, and many farmers have been ruined in fortune, how natural it is to wish that it all could have been avoided; that in some way the adverse elements could have been controlled.

To look for help in such a case from the so-called "rain-makers" is vain, for, even conceding the entirely unproved, undemonstrated claim that they can "make" artificial rain, or, in other words, cause rain to fall where it would otherwise not have fallen, it is sure that in "producing" for one locality they would take away a portion of what rightfully would belong to another.

What more natural than for the mind to turn from such scenes of crop destruction and desolation as the past two months have witnessed in the fertile Mississippi Valley to lands where rain failure in the growing months, though it may cause discomfort and perhaps loss, can not cause widespread disaster. How natural to think of those irrigated districts where the waters of never-failing rivers or inexhaustible lakes are turned into canals and smaller and ever-branching ditches to water the thirsty soil, even as from the large arteries of our bodies branch the ever-ramifying blood vessels to the smallest capillaries to carry food for our wasted tissues. And the thought is suggested, Why, even in our great Mississippi Valley, where harvest is always almost certain, should not the waters of the ever-flowing streams be diverted out over the land to insure certain crops rather than run fruitless toward the sea?

The irrigation idea is not one of the brilliant inventions of the nineteenth century. It almost appears to be coeval with the dawn of agriculture on the planet. Far back beyond authentic history, in Egypt, Assyria, and Mesopotamia immense canals bore water over land much of which is now a desert; in Arizona, and elsewhere on this continent, explorers have found ruins of irrigating canals and reservoirs, which would indicate that long before the discovery of America a civilized people carried on agriculture by irrigation on an immense scale, in comparison with which the irrigation revived but a comparatively short time ago in Utah and other far western States is on a small scale.

Forty-seven years ago the pioneers in Utah (pioneers indeed west of the Missouri) trained the waters of the mountain torrents over a tract of sage-brush desert, imitating the fathers of primeval times. Their success was beyond expectation, and their example in converting a desert into fruitful fields by the use of flowing water was followed by other localities of the arid region, until once barren California has become a land of flowers, blooming orchards, and waving grain, while the neighboring States are little less. What though no rain falls during summer, or scarcely any? The mountain peaks collect the snows of winter, and from them flow the copious streams which, led out over the farms, insure certain production. Possibilities remain of great reservoirs and canals which may reclaim vast areas of land. In 1891 the total acreage covered by ditches was 735,226 acres. The total irrigable land was 2,304,000 acres, leaving an additional acreage susceptible of irrigation of 1,568,774 acres. In other of the arid States or Territories I know not what the ratio is, but would judge it to be much greater in favor of irrigable lands not covered by ditches. Should the bill now pending in Congress become a law the unoccupied arid lands will be ceded to the various States in whose confines they are for purposes of development by irrigation.

The State which would fail to develop its irrigation possibilities and reclaim its arid lands would be making a very grave mistake.

But besides in the arid region I would advocate irrigation in all States, although they were considered fertile, where great droughts are of frequent occurrence or even possible. Even where rain never fails, if irrigation were employed it would probably so greatly increase the productions of the locality as to well pay for the cost, but I think that irrigation in regions where droughts occur is positively imperative, and, so far as can be seen, does not present great difficulties. In Minnesota, Wisconsin, Iowa, Illinois, Missouri, are countless lakes and rivers, while the

Dakotas, Nebraska, and Kansas are not poorly supplied. The slope of the country is everywhere sufficient to make a system of flowing ditches possible. The legal difficulties are not insuperable; rights of way could easily be obtained for water rights; the canals could often be constructed along the public highways. To be sure, methods of farming would change as a result. The farmer now working 80 acres alone could not irrigate more than 20; but his increased productions would many fold pay for the additional help required. Thus the production of our great central States might be increased beyond computation. As the time will surely come when an overflowing population will make all this a necessity, it were better, it seems to me, that the beginning were made now.

The province of the State weather service in this is, I think, that of advocacy and furnishing information. An opportunity should not be missed in State weather service publications of showing what irrigation does, has done, and can do. It is the meteorologist alone who can tell what amount of rainfall can be depended upon to give the water supply for any region. He it is who may reasonably be called upon by the irrigation engineer to furnish the primary data. The weather service of a State should have sufficient available data to enable the water supply of any of its drainage areas to be computed. It should also be able to give adequate figures on temperature and evaporation; soil absorption, too, might also be within its province. For all this, as many well-selected observing stations as are possible are necessary. They should be well distributed along watersheds and the smaller tributaries of the streams, and in mountainous States as far up among the mountains as people live. Snowfall measurements should be made, even at some expense, high up where the streams head among the snow fields.

Is it objected that this is beyond the province of the State weather service? I maintain that none but the experienced, trained, and well-informed meteorologist can properly conduct such work; no one so well understands what an inch of rainfall or a foot of snow means; no one is so well fitted to work up the collected data into totals and normals; no one can so judiciously select and classify the stations. It should, therefore, be State weather service work, and paid for by the State where the State is able, otherwise by the national service.

Three years ago the first irrigation congress of the States of the arid region was held at Salt Lake City, which memorialized Congress to grant the unoccupied public lands to the States in severalty, in trust for the purpose of developing irrigation. Since then annual congresses have been held; the idea has taken root, and is growing; irrigation will yet be, as our crop reporters have frequently stated it to be in Utah, "the order of the day."

With irrigation meteorology is inseparably bound. The original source of all our lakes and streams is precipitation in the form of rain or snow. This is the original water supply. The guarantee to the irrigation engineer of a sufficient and constant water supply is the information furnished by the meteorologist. Such information can best be collected by State weather services. I do not think that the collection and dissemination of such data necessarily conflicts with the work of the irrigation division of this Department, any more than the crop information of our bulletins conflicts with the work of the statistical division. The work of one division merely supplements that of the other.

It is a legitimate aim of the State weather services to ascertain definitely the amount of rainfall that occurs in our several States and Territories and the maximum amount of it that can be rendered available for purposes of agriculture. Should irrigation projects, based on the information collected by the State weather services, succeed in reclaiming a vast amount of hitherto valueless land, and make crops a certain success in regions where now possible droughts render them precarious and uncertain, all the money, time, and thought the services have cost will have been expended to the best advantage.

GEORGE N. SALISBURY,
Observer Weather Bureau, Director Utah Weather Service.

The following paper dealing with the characteristics of Utah in their relation to State weather service work was written by Mr. Salisbury:

CHARACTERISTICS OF UTAH IN RELATION TO STATE WEATHER SERVICE WORK.

Utah! What varied conceptions arise in your minds as this word is read—no two alike, I venture to say, no matter how well versed you may be in its geography, climate, topography, or its history. And this is natural, for all ideas must vary with the point of view. Utah's winters seem mild to the inhabitants of Minnesota and the Dakotas, though they would be extremely rigorous to the natives of Florida or the Carolinas; and our summers with burning sun are yet very comfortable to those accustomed to the sweltering hot months of the Atlantic coast States.

Of its geography, though one may know well the boundaries of the now embryonic State (just hatching from its shell), and be familiar with the location of Great Salt Lake, Ogden, and the Jordan River, yet he may know absolutely nothing of the local geography, of its diversified mountain chains, its hundreds of beautiful valleys, its mighty mountain-walled rivers, its vast deserts and rugged peaks, its forests of pine, fir, and aspen, its mountain snow fields and mirrored lakes, with a thousand sparkling torrents dashing headlong over granite rocks and through tangled copses to be turned through ditches into chosen paths to water and fertilize the valleys, to at last sink in the sands of the desert or lose themselves in the brine of Great Salt Lake and again arise to the sky from its surface. Of its fruitful fields, many, though small, he has little conception unless he has traveled among them. Its history—ah, that is more or less known to all; but charity will not rudely tear aside the veil that kind oblivion is weaving. History, too, varies with the point of view; to the pioneers of Utah their record is all glorious, whatever it may be to others, while the newcomers fancy that they themselves have done all that has been worthily done in the Territory of temples, tabernacles, and presidents. I dwell so at length on this introduction merely to show how different things seem from different standpoints—how different Utah is to the Utah man from what it is to the Eastern man; and doubtless it is the same way in other States.

Utah's well-known unbounded wealth in the metals has made it appear to many exclusively a mineral region, and so it is to the miner. Those who know of its immense mountain pastures, great herds of cattle, and flocks of sheep, think it pre-eminently a grazing country. Truly, from the standpoint of the cattle and sheep men, Utah is a grazing region.

But to the tillers of the soil—who have so patiently grubbed out the sage brush, dammed the mountain torrents, constructed reservoirs, trained their ditches over the fields, built flood gates, and wasteweirs, and service gates, broken the soil, planted orchards and fields, and never failed to harvest some bountiful crop, if only of the plain and unprepossessing potato—it is a paradise of the agriculturist.

It is with agriculture that State weather services have had most to do, although too exclusively, I am inclined to believe. Climate affects all interests, industries, and occupations to a greater or less degree, and although agriculture may be entitled to receive more attention from the State weather service than other pursuits, any possible benefits to the others should not be lost sight of.

Of all the pursuits mining may be justly considered as the one which takes the least interest in climatic work, and as the one hardest to reach with any benefits of the service, notwithstanding its water supply (an essential) is entirely dependent upon climate, and the periods during which development may be profitably done, and ore hauled, can be determined from climatic statistics. The search for the alluring metal is too absorbing to permit of such secondary considerations.

The climatic service in Utah has been principally utilized by agricultural, sanitary, and advertising interests. Of late, however, the accurate details of the service have not been glowing enough for the uses of the railroad pamphlets and the various circulars advertising Utah, but, for reasons best known to themselves or

readily suspected by a weather investigator, they have preferred to use those glittering generalities about climate which allure without betraying. According to my thinking, however, Utah has nothing that need be concealed in the matter of climate, and tourists and settlers would be more attracted and sanitariums sooner built up at our hot springs and resorts by publishing to the world the exact facts.

Utah has, as regards temperature, four distinct regions: First, the valleys on the eastern side of Great Salt Lake, with a mean annual temperature of 50° to slightly above; second, the great plateau region of the central and western parts, with an annual mean below 50° ; third, the extreme north of the Territory, with annual mean of 40 to 45° ; and, fourth, the extreme southwest portion, with annual mean of 50 to 60° . At St. George, in the latter region, the summer temperature sometimes reaches as high as 118° on the hottest day. On very few winter days does the temperature fall below the freezing point, and never below zero.

These divisions of climate are due to the combined effect of latitude, storm direction, and topography. The latter is somewhat peculiar. The Wasatch Mountains, extending to a height of 8,000 feet above the general surface of the plateau, with parallel ranges and many lateral spurs, traverse the Territory from north to south, while the Uintah range, still higher, in the northern part of the Territory, forms a connecting link between the Wasatch chain and the main divide of the Rocky Mountains. The deserts in the western third of the Territory and the principal mountain valleys are 4,000 to 6,000 feet above the sea. The valleys in the extreme southwest are less in elevation, being 2,000 to 3,000 feet above sea level.

Omitting the small streams flowing into Bear Lake, there are but two river systems—those going into the Colorado and those tributary to the great evaporating lakes. All have their sources in the snow fields of the mountains. The streams flowing into the Colorado run, for the most part, in what are known as box canyons, from hundreds to thousands of feet below the general surface, and, therefore, little of them can be utilized in reclaiming that vast area of arid land east of the Wasatch chain. The rivers and mountain streams of the other systems, however, flow through more or less open valleys, and are capable of being utilized to the last drop in watering the soil. The soil is that sort of "gumbo" found beneath sage brush in the Western States, and is of unsurpassed fertility when properly watered. The valleys of lowest elevation produce splendid crops of grain and vegetables, and with proper cultivation the finest quality of such fruits as can endure a winter season are produced.

It is in these valleys, therefore, that the agricultural part of the population (and indeed nearly all of it) live, and so it is with these valleys that the Utah weather service has most to do. For a knowledge of the precipitation of the Territory it is indeed very desirable to ascertain how much rain and snow fall over the desert, and how much, especially of the snows of winter, falls on the mountain peaks; but, manifestly, a volunteer service can not be established where no people live. It is in the valleys, irregular as they are, that stations have to be established. They must be established, if at all, where they can be, and be undertaken by such observers as are willing to give their services gratis. Such men may not be those best fitted in their communities. Usually they are what is termed "weather cranks" by their neighbors, who can see no objective point to any pathway that does not lead directly to a pile of dollars. For only a portion of the population of Utah are, to use a much abused colloquialism, "out there for their health." In the mining towns none are willing to give their time, which to them means money, or such as might are too rough and unintelligent for the purpose. In the cities the professional men, while best fitted for the work of observation, are too busily occupied in chasing the exceedingly nimble and fast-receding dollar.

So, such weather service as there is has collected its corps of voluntary observers by a similar process to what is named by scientists, "natural selection and survival of the fittest." Some, unpromising at first, have become in time very good, and others starting well, soon tired of the work and became inefficient.

The city newspapers have, as a rule, done much to foster the service, while the indifference of the mining interests and the conservatism of a large element of the population have, undoubtedly, had their effects. In overcoming such adverse influences, local pride, and also the personal pride of the observer, have to be appealed to. Time will gradually accustom these communities to the service so that it will appear to them indispensable.

Under such circumstances, and with such materials, the climatic statistics of Utah have been collected. You readily understand how the mountainous character of the country has prevented much railroad and telegraph extension, and how the consequent poor mail and telegraph facilities have hindered both the collection and distribution of data. Nothing done by the service has so taken the popular fancy as the weather crop bulletins. The farmers have delighted to report their crops, and eagerly scan the bulletins. One reporter informed me that several of his neighbors, discouraged by the poor crops of last year, would have moved away, had they not seen by the bulletins that it was a poor year throughout the Territory. The daily papers have given great prominence to the bulletins.

How far, it may be asked, can the Service be advantageously extended in a territory of 84,750 square miles, of which only 750,000 acres are under cultivation? I would advocate that not only the inhabited districts be represented by voluntary observers, but that paid observers be located on the mountains and deserts until the climate shall be well determined. This should properly be done by the State, but if not done by the State it ought to be done by the National Service. With a systematic development of the arid but tillable land yet unirrigated, the extent of the inhabited territory may be doubled, and the Service correspondingly increased.

In this development the Weather Service ought to have an important part in furnishing precipitation data which hydraulic engineers may use to calculate the water tributary to their storage reservoirs or the streams from which their canals are taken.

The distribution of forecasts in a country like Utah, where the farmers regularly water their crops whether it rains or shines, is of less importance than in other countries, and it is difficult to see their utility, except as storm warnings and frost and cold-wave warnings. The grazing industry, however, could be largely benefited by well-timed warnings. There ought to be more security for the immense flocks of sheep and herds of cattle that now graze in the elevated valleys. Warnings of severe storms and cold waves could and should be given two days in advance.

So much for Utah's climate, resources, and possibilities of State weather service work, and yet the half has not been told. Without the spirit of prophecy, one who runs may read that with returning prosperity throughout the country, a career of wonderful development is about to open for Utah. Her mines will be worked to full capacity, railroads will be built, the wheels of industry will turn, her acreage under cultivation will double, great harvests of fruit will yet be produced, her bountiful wheat harvests will continue, her cities become populous, her common schools and educational institutions equal the finest in the land. Thus, out of the desert will arise a great empire State—a bright particular star in the galaxy of States. May it be so, and with such advancement may the Utah weather service keep pace, being ever an important factor in that development.

GEORGE N. SALISBURY,
Utah Weather Service, Salt Lake City, Utah.

Mr. F. P. Chaffee, of Montgomery, Ala., regretted his absence, but discussed to some extent the fifth topic in the following letter to President Dunwoody:

MONTGOMERY, Ala., August 12, 1894.

Maj. H. H. C. DUNWOODY,

President American Association of State Weather Services,

Washington, D. C.

SIR: Owing to causes beyond my control, I will be unable to attend the convention of the association to be held at Brooklyn, N. Y., during the present month. While regretting my inability to be present, I must say that the meeting has my hearty sympathy in its work, which, like those of previous meetings of the association, can only result in the improvement of the State weather services of the country, and increasing the benefits derived therefrom.

In reference to the fifth topic for discussion of the third annual convention of the association—"Monthly publication of State weather services: (a) Should the publication of monthly reports containing advertisements be encouraged?"—I would submit the following:

As understood by the writer, the only cases in which advertisements appear in such publications is where there has been a demand for such an increase in the publication of the monthly reports as could not be well met with the crude and laborious method of issuing them by the milligraph and similar duplicating processes, and where no State aid is furnished to print the reports.

In such cases the advertisements are a matter of necessity, as they pay for the printing and other expenses incident to the publication.

It is thought that there is hardly a case where the maintenance of such publications has been a matter of profit, and in many such cases, it is thought, they have been of some pecuniary loss to those publishing them.

The advantage of printed publications over milligraphed reports is very evident. They present the information in more attractive and more readable shape, admit of a much wider publication, and are a means of creating more interest in the work among the voluntary observers and the general public.

Knowing the advantages of printed publications, it would seem that, should the maintenance of the printed monthly reports by advertisements be discouraged where no State aid can be obtained for such publications, some other means should be provided for printing these reports. With this end in view, I would suggest the following:

That where no State aid is furnished the State weather services, that the monthly reports of such services be printed at the central office of the National Weather Bureau, and a sufficient number of copies of the same be furnished the directors of the State weather services for distribution. The Monthly Weather Review of the National Bureau now publishes a portion of the detailed data of the voluntary reports of the various State weather services. By increasing this, and devoting, say, one page of the Review to the reports of each of the State services, the Monthly Weather Review would be made more complete and more valuable as a statistical publication, and advance sheets of such pages could be printed and forwarded to the various State weather service centers, where they would serve very nicely for monthly reports.

Such a system would not be very expensive, and would entail no great delay in publication, as many of the monthly reports of the State weather services are now published several weeks after the month of which they form a record, and it would have the advantage of insuring quite a uniformity in the reports.

The "copy" for these reports could be made up at the State weather service centers and forwarded to Washington by the 10th of the succeeding month, and could probably be printed and copies returned for distribution as quickly as the reports of many of the State weather services are now published.

I inclose herewith a sample of about how such a report as just suggested should be made up. This might be considerably contracted, by condensing both the summary and the table. The daily temperatures and the daily rainfalls are not given in this sample, as it is not considered necessary, as a record of such data can be kept at the central stations, from which demands for such information can be met.

It is understood that a number of objections might be offered to the method suggested above, but it is mentioned with a view of exciting just such criticism, from which might evolve some better method of printing the monthly reports of the State weather services.

Very respectfully,

F. P. CHAFFEE,
*Local Forecast Official, Weather Bureau,
Director Alabama S. W. S.*

Upon motion of Mr. Jennings, duly seconded, the constitution¹ was amended as follows:

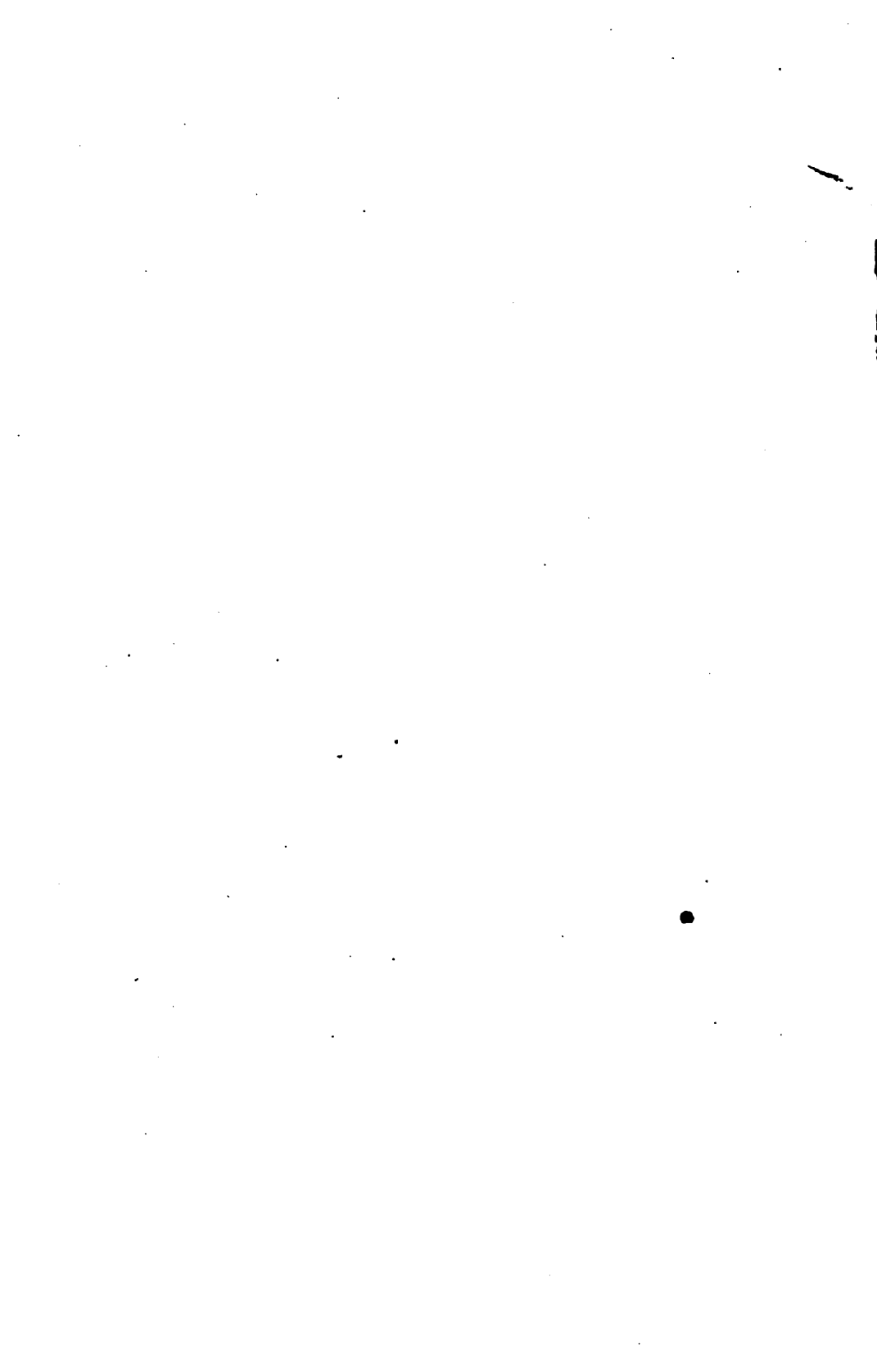
After section 1, Article II, add: "Provided the President may have power to call the meeting at some other time and place."

OFFICERS OF THE ASSOCIATION.

The election of officers for the ensuing year, as below, concluded the work of the convention:

President, Maj. H. H. C. Dunwoody, U. S. A., assistant chief of Weather Bureau, Washington, D. C.; first vice-president, T. F. Townsend, Weather Bureau, assistant director Pennsylvania weather service, Philadelphia, Pa.; second vice-president, S. W. Glenn, local forecast official, director South Dakota weather service, Huron, S. Dak.; secretary and treasurer, James Berry, chief State weather service division, Weather Bureau, Washington, D. C.; executive committee, Messrs. J. Warren Smith, director New England weather service, Boston, Mass., Mr. E. W. McGann, director, New Jersey weather service, New Brunswick, N. J., and Dr. C. P. Cronk, meteorologist in charge Maryland weather service, Baltimore, Md.

¹ See First Annual Report, American Association of State Weather Services.



Bulletin No. 15.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

PROTECTION FROM LIGHTNING

BY

ALEXANDER MCADIE
U. S. WEATHER BUREAU.



WASHINGTON, D. C.:
WEATHER BUREAU.
1895.



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**U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.**

PROTECTION FROM LIGHTNING

BY

**ALEXANDER MCADIE,
U. S. WEATHER BUREAU.**



**WASHINGTON, D. C.:
WEATHER BUREAU.
1895.**

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., March 18, 1895.

SIR: I have the honor to transmit herewith a revised copy of the circular of information entitled "Protection from Lightning," and to recommend its publication as a Bulletin of the Weather Bureau.

Very respectfully,

MARK W. HARRINGTON,
Chief of Bureau.

Hon. J. STERLING MORTON,
Secretary of Agriculture.



LETTER OF SUBMITTAL.

WASHINGTON, D. C., *March 11, 1895.*

SIR: I have the honor to submit for publication a revised copy of the pamphlet entitled "Protection from Lightning." Upon few subjects is the community so liable to be misled as on that of the best methods of protecting life and property from lightning. The following pages give statistics of actual losses, the theory of protection in language—free from technicalities, and directions for procedure in cases of apparent death from lightning stroke. A collection of practical rules for guidance in selecting and maintaining conductors, and a notable instance in the case of the Washington Monument of the successful use of protectors, are also given.

The aim of the paper is to furnish information of practical value to all classes, and especially to farmers, builders, and physicians.

Very respectfully,

ALEXANDER MCADIE.

MARK W. HARRINGTON,
Chief of Weather Bureau.

PROTECTION FROM LIGHTNING.

At the Aberdeen meeting of the British Association for the Advancement of Science Sir William Thomson made the remark, "If I urge Glasgow manufacturers to put up lightning rods they say it is cheaper to insure than to do so."

This was the answer given by practical business men, concerned only with questions of profit and loss, to the foremost physicist of our time; and their answer will serve as fairly representing views widely held, founded upon the double belief that the risk from lightning is not so very great and the protection afforded by the present methods not sufficiently certain to warrant implicit confidence and justify the necessary expense.

The recent remarkable experiments of Dr. Oliver Lodge, in his lectures before the Society of Arts, opposing and to some degree directly contradicting the empirical rules of the Lightning Rod Conference, have given support to the belief that the protection was uncertain. Indeed, realizing that his work might be misinterpreted, Lodge has stated "an idea at one time got abroad that my experiments proved existing lightning conductors to be useless or dangerous; this is an entire misrepresentation. Almost any conductor is probably better than none, but few or no conductors are absolute and complete safeguards. Certain habits of lightning rod practice may be improved and the curious freaks or vagaries of lightning strokes in protected buildings are intelligible without any blame attaching to the conductor; but this is very different from the contention that lightning rods are unnecessary and useless. They are essential to anything like security."¹

What Lodge's brilliant experimental work does show is that the momentum of an electric current can not be overlooked in a lightning discharge. The old "drain-pipe" idea of conveying electricity gently from cloud to earth must give place to the new proposition, based upon recent discoveries, that even draining off must be done in an appropriate way to be effective. To illustrate, the rocks and trees upon a mountain side may influence and determine the course of a mountain stream, but even a good sized channel would not suffice to carry off safely an avalanche, or control the path of a landslide; so with lightning. In the past four years we have learned, through the work of Hertz and others, that when an electric current flows steadily

¹ Page VI. "Lightning Conductors and Lightning Guards."

in one direction in a cylindrical wire its intensity is the same in all parts of the wire; but if the current be of an oscillatory character, i. e., a current which rapidly reverses its direction, the condition no longer holds, and if the alternations are very rapid the interior of the wire may be almost free from current. If lightning then be a discharge of an oscillatory character, it may happen that the current down the lightning rod would be only *skin* deep. The experiments of Tesla and Elihu Thomson with currents of great frequency of alternation and very high potentials open the door to systematic study of discharges such as the ordinary lightning flash. In daily work currents of this type are coming more and more into prominence, and the time is not far distant when the lightning flash will be studied as an electrical discharge of this character. Protection entirely adequate for such discharges will then be forthcoming. Indeed, the reasons why present methods occasionally fail are now understood, and the proper remedies apparent.

And first let us see whether it is cheaper to insure than to provide proper protection. Foreign countries, especially Germany, France, and Great Britain, have recognized the importance of obtaining reliable data concerning the loss of life and damage to property through lightning. Perhaps the work of the Royal Prussian Bureau of Statistics¹ gives the fullest and most detailed accounts of the damage done by lightning in Germany, and the relative injury. Statistics are available for the number of houses struck, the number of fires, the character of the roofing, soil, etc.

In 1891 the Weather Bureau issued to its observers instructions to report at the end of every month the names, with corroborative dates and places, of all persons killed by violent windstorms, tornadoes, and lightning. During 1890 somewhat similar statistics had been gathered, but the returns were less systematically arranged. In preparing the Weather Bureau lists, observers were directed to examine all daily papers published in their respective cities, consult all local authorities, and make inquiry if necessary. Naturally, where dependence was had upon newspaper items, there resulted much duplication, but in verifying names and dates the duplicates quickly appear and exaggerated reports are easily confined to proper limits.

From the Weather Bureau records which have been tabulated, it appears that in the United States, for the five years 1890-'94, 1,120 lives were lost, an average of 224 lives per year.

It is also evident that these lives were practically all lost in five months—April to September—and that in June and July the maximum death rate occurs.

The Weather Bureau records unfortunately do not give informa-

¹ Beiträge zur Statistick de Blitzschläge in Deutschland; by Dr. Hellmann, Berlin, 1886.

tion as to the extent of damage to property. To get at something like a fair commercial estimate of the destruction of property by lightning, I have made use of the "Chronicle Fire Tables" for the nine years 1885-'93. It is hardly necessary to remark that these tables are compiled from the reports of the fire departments, insurance companies, and the reports of fires in the public press, and represent a high degree of accuracy.

From information contained in these volumes, the following tables have been compiled :

Fires caused by lightning.

Year.	Number of fires.	Loss.
1885 to 1890, inclusive	2, 220	\$8, 386, 826
1891.....	457	1, 355, 525
1892.....	839	2, 921, 484
1893.....	659	1, 645, 180

Or, in nine years, ending 1893, in the United States, and for the most part east of the Rocky Mountains, 4,175 fires, with a loss of \$14,309,015.

It is very evident, therefore, that the damage done by lightning is no inconsiderable matter, to be lightly passed over or turned off by replies such as the one given by the Glasgow manufacturers. It is certainly worth while to erect the proper protective apparatus.

The following table shows the number of barns, stables, granaries, churches, and dwellings set on fire by lightning during the years 1890, 1891, 1892, and 1893 :

Barns, churches, and dwellings fired.

Year.	Barns, stables, and granaries.	Churches.	Dwellings.
1890	363	29	121
1891	290	11	78
1892	495	29	177
1893	344	25	167

During ten years ending 1893, 2,679 barns, 129 churches, and 831 dwellings have been struck by lightning.

The question has often been raised whether there exists a periodicity in the number of lightning strokes. Statistics must cover a period of at least twenty years before an answer to this question can be given, but it is interesting to compare the number and kind of buildings struck for the last three years of which we have record.

Comparison of buildings set on fire.

	1891.	1892.	1893.
Barns, granaries, and stables	290	495	344
Churches	11	29	25
Country and general merchandise stores	5	6	8
Dwellings and tenements	78	177	167

Comparison of buildings set on fire—Continued.

	1891.	1892.	1893.
Electric light stations.....	1	2	1
Grain elevators.....	2	4	2
Grain fields.....	1	.....	0
Grain, hay, and straw in stack.....	10	12	7
Ice houses.....	4	4	1
Lighthouses and life-saving stations (no other source of fire reported)....	2	.....	0
Livery stables.....	4	4	1
Lumber yards.....	2	1	0
Oil refineries.....	2	2	1
Oil tanks.....	2	22	7
Railroad depots.....	5	7	15
Telegraph and telephone offices.....	2	3	4

It is of particular interest to study the geographical distribution of the dwellings and barns *fired by lightning* in these three years. There are some notable increases in certain States, the reasons for which are not at present discernible. Attention is directed to the figures in bold-faced type, showing a marked increase as compared with the previous year.

Geographical distribution.

State.	Barns.			Dwellings.		
	1891.	1892.	1893.	1891.	1892.	1893.
Alabama.....	0	0	1	2	0	5
Arizona.....	0	0	.....	0	0	.....
Arkansas.....	0	0	1	1	0	0
California.....	0	0	1	0	0	0
Colorado.....	0	.....	.....	0	0	0
Connecticut.....	9	25	12	6	16	4
Delaware.....	4	5	1	.....	.....	0
District of Columbia.....	0	0	0	0	0	0
Florida.....	0	0	0	1	3	3
Georgia.....	0	0	4	2	2	3
Idaho.....	0	0	0	0	0	0
Illinois.....	17	7	80	7	12	10
Indiana.....	31	38	29	7	9	12
Indian Territory.....	0	0	0	0	0	0
Iowa.....	19	6	7	.....	.....	4
Kansas.....	1	2	2	.....	.....	1
Kentucky.....	3	4	4	.....	.....	1
Louisiana.....	0	0	0	3	4	0
Maine.....	21	23	13	7	16	3
Maryland.....	12	8	12	.....	8	2
Massachusetts.....	12	15	13	8	12	11
Michigan.....	26	70	35	.....	13	14
Minnesota.....	7	5	3	4	6	3
Mississippi.....	1	.....	0	.....	.....	2
Missouri.....	2	1	11	2	3	10
Montana.....	0	0	0	0	0	0
Nebraska.....	1	.....	10	.....	.....	2
Nevada.....	0	0	.....	0	0	0
New Hampshire.....	2	2	7	.....	.....	1
New Jersey.....	14	80	10	3	7	7
New Mexico.....	0	0	.....	0	0	0
New York.....	30	117	59	5	25	26
North Carolina.....	2	3	1	.....	2	2
North Dakota.....	0	1	1	0	0	0
Ohio.....	26	26	18	6	4	13
Oregon.....	2	.....	0	.....	.....	0
Pennsylvania.....	29	75	23	3	25	3
Rhode Island.....	1	4	3	.....	2	8
South Carolina.....	3	.....	0	.....	.....	.....
South Dakota.....	3	3	0	2	2	0
Tennessee.....	0	0	2	0	1	1
Texas.....	4	7	4	.....	.....	5
Utah.....	0	2	0	0	0	0
Vermont.....	0	3	3	0	0	3
Virginia.....	4	.....	6	.....	2	1
Washington.....	1	0	0	1	0	0
West Virginia.....	1	2	1	0	1	0
Wisconsin.....	6	11	27	2	3	8
Wyoming.....	0	0	.....	0	0	0

The statistics collected by the observers of the Weather Bureau show, in addition to the number of fires and estimated damage, the number of lives lost, the number of persons injured, and such other facts as seem of particular value in connection with lightning.

LOSS OF LIFE AND DESTRUCTION OF PROPERTY BY LIGHTNING IN THE UNITED STATES IN 1894.

In January no lives were lost so far as known.

In February 2 lives were lost, 2 persons injured, and 50,000 feet of lumber destroyed.

In March 6 lives were lost, 3 persons injured; and 2 barns, 2 churches, and 5 dwelling houses struck and damaged.

In April 14 lives were lost, 15 persons injured; 1 barn and 7 dwelling houses damaged.

In May 55 persons were killed by lightning and 34 severely injured; 12 houses were set on fire with a loss of not less than \$35,000; 36 dwellings, 4 churches, 2 school houses struck, and more or less damaged; 58 horses and 22 cows not in stables were killed.

In June 96 persons were killed and 102 severely injured; 69 barns were damaged not less than \$49,000; 49 houses, 30 cows, and 15 sheep not stabled were killed; 80 dwellings, 22 churches, 1 railroad depot, 1 oil tank, 1 grain elevator, 6 mills and factories were damaged; the loss in the eight last named being not less than \$257,000.

In July 60 lives were lost, and 103 persons injured; 46 barns were damaged not less than \$50,000; 45 dwellings, 12 churches, 2 academies, 3 mills or factories, and 2 railroad depots were struck; 24 horses and 13 cows, 5 mules, and 6 sheep, not stabled, were killed.

In August 78 lives were lost and 76 persons injured; 81 barns were burned with a loss of not less than \$129,800; 41 dwellings were struck, 22 horses and 15 cows, not stabled, were killed; 5 churches, 2 academies (one with loss of \$38,000), 2 mills, and 1 oil tank (loss \$20,000) were struck.

In September 99 persons were killed and 14 severely injured; 56 barns were struck with loss of not less than \$141,500; 42 dwellings, 2 churches were struck, 14 horses, not stabled, were killed.

In October 6 persons were killed and 2 severely injured; 2 barns valued at \$3,000, 2 dwellings, 2 churches, and several stacks of grain were fired.

In November 1 dwelling was struck, valued at \$3,000.

In December 1 barn in Ohio, 2 dwellings (one in San Francisco, Cal., where damage from lightning is almost unknown), were struck.

During the year 336 persons were killed and 351 severely injured; 268 barns struck with a damage of \$407,500; 55 churches were struck, damage unknown; 261 dwellings and several oil tanks, factories and elevators, the damage amounting to not less than \$351,000.

For purposes of comparison the following table has been prepared :

Loss of life in the United States by lightning.

	1890.	1891.	1892.	1893.	1894.
January.....					2
February.....					6
March.....	2			5	6
April.....	6	13	5	19	14
May.....	8	23	27	17	45
June.....	37	73	74	66	96
July.....	55	52	67	73	60
August.....	127	34	54	18	78
September.....		9	15	8	29
October.....			6	2	6
November.....			1		
December.....			2	1	
Total.....	1207	204	251	209	336

According to the statistics of the German bureau, previously referred to, the frequency of lightning stroke varies somewhat with the character of the land. Thus, in their investigations it was found that in flat lands 400 to 540 buildings were struck out of 1,000,000, the rate varying in different localities.

The nature of the material used for roofing has also been considered. Classifying the various materials under the general heads "hard" and "soft," the German investigators found for ten years (1873-'83) for Schleswig-Holstein, that of all the buildings struck, 9 per cent of those having *hard* roofs and 68 per cent of those having *soft* roofs were set on fire. The nature of the building and the purpose for which it is used will, as we readily see also in our own statistics, influence the liability to stroke and fire.

The following facts¹ regarding the distribution of thunderstorms are of interest, though it is to be noted that the damage done may not be directly proportional to the number of storms :

The region of the greatest number of thunderstorms is in the southeastern part of the United States. The line for 40 per year passes through southern Georgia, southern Alabama, and southeastern Mississippi. The number increases northeastward and the area in which less than 10 thunderstorms occur each year is confined to the coast of New England. * * * From May to June the maximum is in the northeastern and central States, especially in a region extending along the Mississippi Valley from Keokuk to Cairo. * * * For July the maximum extends from northern Montana to central Texas, thence to Georgia and thence northeastward to southern Maine; also in a small area about Lake Huron. The maximum for August occurs in the vicinity of Salt Lake, Utah, and along the Gulf and Atlantic coasts. It appears, therefore, that the maximum of thunderstorms comes earliest to the west and southwest of the Great Lakes, and gradually extends to the west, south, and east. A matter of especial interest is the occurrence of winter thunderstorms. The area of maximum frequency is in Louisiana and vicinity. * * * The general direction of approach in the United States is from the west. At Key West, Fla., the approach is from the east; at Galveston, Tex., from the northeast, north, or southwest.

¹ Rainfall and Snow of the United States, p. 29, by Mark W. Harrington, Chief of U. S. Weather Bureau.

One interesting point which appears to be shown by statistical studies of lightning stroke is the decreased liability to accident in *thickly settled communities*.

It may be said, in general, that the risk in the country is five times greater than in the city. For ordinary dwelling houses, not unduly exposed in city blocks, lightning rods are hardly necessary, a very considerable protection being afforded by the tin roofing, numerous cornices, gutters, etc. The geological, as well as the topographical conditions, may have some influence upon the frequency of lightning stroke. According to the authority already quoted, if 1 represents the frequency of lightning stroke in a chalk formation, 2 will represent the liability for marl, 7 for clay, 9 for sand, and 22 for loam.

With regard to trees, the oak is most frequently, and the beech least frequently, struck. The values are something like, if 1 represents the frequency for the beech tree, 15 for pines, other trees generally averaged at 40, and 54 for oaks. Trees struck are most generally those standing in the clear or on the edge of forests, and in height averaging from 16 to 20 meters (52 to 66 feet). The trunk appears to be struck about three times as often as the boughs, and generally the stroke seems to travel to the ground. Only in three out of a hundred cases did it jump to other trees.

Mr. Symons,¹ in his paper on thunderstorms, instances 16 trees struck. About one-third of these were elms, with the oak, ash, poplar, in order following, and one case each of crab-lime and willow.

It is interesting to recall at this point, the record made by Hugh Maxwell as early as 1787, that the elm, chestnut, oak, and pine were often struck, the ash rarely, and the beech, birch, and maple never. This last, however, is not true. Indeed, it is not altogether plain just why some trees escape while others suffer. Capt. Maclear,² discussing the action of lightning during a thunderstorm on June 6 and 7, 1889, found a great number of trees struck within a radius of 4 miles, and set to work to discover if possible the cause of the selection of these particular trees. "For contrary to general expectations," he says, "they were not the highest nor the most prominent in their immediate vicinity." A cottage, a haystack, 2 poplars, a spruce, fir, and 5 oaks, in different places, were struck within this confined area.

The storm passed in a northwest direction with southeast wind, and it is apparent that the objects struck lie nearly in a line northwest and southeast, 3 miles in length. "The spruce was very prominent on the southern brow of the hill, with two arms nearly in line with the stem; one arm was thrown to the ground and the other

¹ Also, Appendix E. "Report of Lightning Rod Conference."

² "Quart. Journ. Met. Soc." 1890, p. 229.

blown down. At the juncture of the arms there was a great deal of turpentine which was thoroughly blackened." Hence, it is assumed that the prominence of the tree made it the best communication to earth, and that the collection of turpentine was raised to explosive temperature and split the tree, but a like good reason does not appear for the other objects struck. On the next day 6 oaks, a chestnut, and an ash, in various positions within one-half mile of a pond, and on the slope of ground near the pond, a young fir, and three young oaks; one-half mile south of Cranleigh 4 oaks; on Cranleigh Common an oak, and 1 mile northwest a chimney, a stable, and an oak (struck also on the day before) and a single oak occupying a fairly prominent position on the slope of high hills, 2½ miles northeast.

This last tree was struck just before the rain commenced and was split; the other trees struck during the rain were only scored. "Hence," concludes Maclear, "it is not easy to see the cause of selection, for these trees were not the most prominent, nor were they on the highest ground in the vicinity, *the only feature the groups possessed in common being that they were all either near ditches which were full of running water, or else near temporary courses taken by the deluge of water from the higher to the lower ground.*¹ The most puzzling case is that of the young fir tree and 3 young oaks in the middle of the copse near the pond. They were not higher than the other trees on the copse, but there certainly was a temporary water course close to them; other trees, however, stood equally close to water. * * * Another curious case is that of the stable struck, which was overshadowed by tall elms, where it might have been supposed that these would have taken the stroke."

Some statistics of the damage done by lightning stroke in Belgium* in 1889 may be appropriately inserted here. Of 324 lightning flashes, 2 struck lightning rods; 123 struck buildings, setting 36 on fire; 16 struck persons; 96, trees; 81, telegraph and telephone lines; and others, miscellaneous. In other statistics we find that of 18 deaths due to lightning; 1 occurred within a dwelling, 11 out of doors, and 6 under trees. Contrasted with the cases of death resulting from lightning stroke, let us look at 43 cases of persons struck, with results not necessarily fatal, and we find that 20 of these were in doors, 23 out of doors, including 4 under trees. No records sufficiently extended and authentic are available to ascertain what proportion of persons struck by lightning are killed outright. I know of but one record, and in that of 212 persons struck 74 were killed. This question, which is of the greatest interest, is referred to again under the last of the rules given further on for the protection of life.

One of the peculiar and most common characteristics of the action

¹ Italics mine.

* Evrard and Lambotte. *Ciel et Terre*, 1891; No. 7.

of lightning is the *tearing off* or *throwing* effect. This, as we shall see further on, is just what might be expected from discharges of great frequency of alternation. Some interesting statistics are given by Parnell¹ on the mechanical tearing off and disruptive effects of lightning as distinguished even from the *heat* effects. He records 1,147 cases. Of these, 224 do not permit a determination of the character of the work done by the stroke of the remaining 923.

	Mechanical work.	Heat.
Persons and animals.....	52	79
Cloths, carpets, canvas, woolen, linen, and cotton goods.....	88	79
Masonry of all kinds.....	416	2
Glass, china, earthenware.....	82	5
Metal.....	206	173
Wood.....	254	98
Trees.....	63	4
Ground.....	60	.....
Thatch, straw, etc.....	.....	11
Gunpowder.....	.....	15
Gas.....	.....	19
Total.....	1,221	485

Col. Parnell gives, furthermore, the details in 278 cases to show the existence of an *upward* direction in the force of the stroke.

This, and the statement that "probably few persons are aware that lightning strokes are more apt to bend or break metal than to fuse it," are, in the light of the investigations of the past three years into the character of the lightning flash, easily comprehensible. A lightning flash being a break in the air (i. e., the dielectric) when the electrical strain exceeds a certain value, determined by several variables, the strongest mechanical effect may be found in any direction, upward or downward. Speaking popularly, flashes may go from cloud to earth, earth to cloud, or from cloud to cloud to earth.

II.—THE THEORY OF LIGHTNING CONDUCTORS.

Beyond doubt, Franklin proved his case that lightning rods were efficacious in the protection of buildings. An illustration of the action of lightning upon a rod is shown in Fig. 4. Buildings with conductors when struck by lightning suffered little damage compared with those without protectors.

The chief defects likely to occur are blunted points and breaks in the continuity of the connection. The function of a lightning rod is twofold; first, that of conducting the charge to earth, and second, the prevention of a disruptive discharge by silent neutralization of the cloud electrification. The latter explains why a rod terminates in a point and likewise why points in good connection with the ground are always *desirable* upon buildings. Indeed, points are somewhat like small water pipes connected with a large reservoir. If you have

¹ "Quart. Journ. Met. Soc.," Vol. vi, 1886. See also Col. Parnell's book.

enough of them and a sufficient time you may drain the largest reservoir. Furthermore, when some sudden rise or flood occurs in the reservoir, these minute drains may be of service in keeping the height of the water down.

In the case of lightning the points are the small escape pipes, the layer of air between cloud and earth the retaining wall, and the cloud electrification—or charge—the overflowing and destructive element. A large conductor, be it rod or tape, on the other hand is more like a large main or water way, which has its gate shut until the flood is imminent. Then the gate is suddenly opened and we try to compel the torrent to keep to the provided path. We trust in its ability to safely hold the flood. Generally it does. In perhaps nine cases out of ten, the lightning conductor, if it be such a one as we will describe later, does carry the flash to earth; but there are cases where the discharges have been heavy and overflows have resulted. To carry the lightning flash “the lightning conductor should offer a line of discharge more nearly perfect and more accessible than any other offered by the materials or contents of the edifice we wish to protect.” To prevent the discharge “the conductor should be surrounded by points.” These quotations are from the Report of the Lightning Rod Conference.

The statement that lightning always follows the path of least resistance, as commonly understood and stated, needs modification. True it is, that when the air is strained by being subjected to the electrifications of cloud and earth, the weakest spot gives away first, and this is apt to be in line with some small elevated knob or surface; but it is equally true, and is perhaps the more general case, that when a really vigorous disruptive discharge does occur, it is somewhat, as Dr. Lodge aptly puts it, like an “avalanche.” As a matter of fact, we find from the study of actual cases where buildings have been struck, that lightning often disregards entirely metallic surfaces and points. What we should first know is, whether the condition is to be one of “steady strain”¹ or “impulsive rush”¹ discharge. In the case of “steady strain,” the metal is apt to influence the path of discharge; in the case of an “impulsive rush” discharge, even *points* seem to lose their efficiency and become of little use.

In a letter² of an old British admiral there occurs a description of his being called upon to approve some specifications for a lightning conductor to be erected on a certain lighthouse. He was himself a believer in the “surface” theory of Harris; but thought that, to make sure, he would go and consult his friend Faraday. Faraday, who saw only the question of conductivity in the problem, said very positively that the solid rod was better than the tube (which gives

¹ Terms used by Prof. Lodge.

² See report of Lightning Rod Conference.

greater surface with less copper), and that *solid volume was everything*, superficial area nothing. Moreover, if Harris says otherwise "then, he knows nothing whatever about it." The admiral straightway approved the solid rod conductor for the lighthouse. Within two or three days he met Harris, and bringing up the question was told by Harris "*surface area is most important, and if Faraday says otherwise, then he knows nothing whatever about it!*"

Up to a certain point Faraday was right; a copper rod an inch thick is capable of carrying almost any flash of lightning, and is undoubtedly a great protector, but if, as we have reason to believe, the core is seldom given a chance to carry the current, why have it? The views of Sir W. Snow Harris, based as they were upon close study of many thousand cases of lightning action, are finding in the experiments of to-day the confirmation so long needed.

While not going into details regarding this question of the shape of the rod, let us emphasize the fact, so recently brought out, that if an electric current flows steadily in one direction in a cylindrical wire, its intensity is the same in all portions of the wire, as shown by Hertz, but that with a current of an oscillatory character, i. e., a current which rapidly reverses its direction, this condition no longer holds, and if the direction is altered very rapidly the interior of the wire, in our case the lightning rod, may be almost free from current.

In 1882 appeared the report of the Lightning Rod Conference; in many respects the most important contribution to the literature of the subject yet made. While so many foreign governments, and in particular France, had by means of officially constituted boards taken a governmental interest in the protection of the people from the dangers of lightning, the English-speaking people of the world aside from the few directions officially issued for the protection of magazines and lighthouses, remained without any authoritative utterance upon the subject; and while this conference itself did not have strictly official sanction, it carries, from the character of its make-up, a weight certainly as great, if not greater, than an official board. It was simply a joint committee of representative members of the Institute of British Architects, the Physical Society, the Society of Telegraph Engineers and Electricians, the Meteorological Society, and two co-opted members. As might be anticipated from such auspices, the report is an excellent one, and must stand for years as the embodiment of the most widely gathered information and well-considered decisions. The report is emphatically one based upon *experience*.

The famous free-for-all discussion which occurred at the British Association Meeting in 1888, so far as our judgment goes, simply proved that the decisions of the conference could not at present be disregarded. As the president of the meeting, Sir William Thomson

said, we have "very strong reason to feel that there is a very comfortable degree of security, if not of absolute safety, given to us by lightning conductors made according to the present and orthodox rules."

There are one or two further features to which attention may be called. There are some very prevalent misapprehensions with regard to lightning. For example: that it never strikes twice in the same place; that the most exposed place is always struck; that a few inches of glass or a few feet of air will serve as a competent insulator to bar the progress of a flash that has forced its way through a thousand feet of air, etc. These are alluded to in the following general directions.

III.—RULES FOR THE ERECTION AND MAINTENANCE OF RODS.

1. Erection of rods. Few questions have been so thoroughly discussed from practical as well as theoretical standpoints as that of the certainty of the protection afforded by properly constructed lightning rods. All barns and exposed buildings should have lightning rods. Ordinary dwelling houses in city blocks have not the need for rods that scattered houses in the country, and especially if on hill sides, have.

2. Use a good iron or copper conductor. If the latter, one weighing about 6 ounces to the foot, and preferably in the form of tape. If iron is used and it seems to be in every way as efficient as copper, have it in rod or tape form and weighing about 35 ounces to the foot. "A sheet of copper constitutes a conductive path for the discharge from a lightning stroke much less impeded by self-induction than the same quantity of copper in a more condensed form, whether tabular or solid." (Sir William Thomson.)

3. The nature of the locality (see Chapter I) will determine to a great degree the need of a rod. Places apart but a few miles will differ greatly in the relative frequency of flashes. In some localities the erection of a rod is imperative; in others, hardly necessary.

4. The very best ground you can get is, after all, for some flashes but a very poor one; therefore, do not imagine that you can overdo the matter in the making of a good ground. For a great many flashes an ordinary ground suffices, but the small resistance of $\frac{1}{16}$ ohm for an intense oscillatory flash may be dangerous. Bury the earth plates in damp earth or running water.

5. "If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another it is best to connect them metallicly. The neighborhood of small bore fusible gas pipes and indoor gas pipes in general should be avoided." (Lodge.)

6. The top of the rod should be plated or in some way protected from corrosion and rust.

7. Independent grounds are preferable to water and gas mains.

8. Clusters of points or groups of two or three along the ridge rod are recommended.

9. Chain or linked conductors are of little use.

10. Area of protection. Very little faith is to be placed in the so-called area of protection. The committee that first gave authority to this belief considered that the area protected by any one rod was one with a radius equal to twice the height of the conductor from the ground. Many lightning rod manufacturers consider that the rod protects an area of radius equal to the height. The truth is that buildings are struck sometimes within this very area, and we now hold there is no such thing as a definite protected area.

11. Return shock. Some uncertainty exists on this point. The so-called "return stroke" is caused by the inductive action of the charged cloud on bodies within its influence, and yet some distance away from the place of the direct discharge. As explained by Lord Mahon, who first called attention thereto, the sudden return of the body charged inductively to a neutral condition, following the equalization at some distant place, is the cause of the return shock. We are beginning, however, to see more clearly into the character of the stress in the dielectric, preceding and during flashes, and it is only a question of time before the use of this term, "return shock," will be abandoned. Of far greater import are the terms "recoil kick" and "alternative path," as shown experimentally by Lodge to exist.

12. Upward motion of stroke. There is no reason to doubt that the discharge takes place sometimes from earth to cloud. That is to say, that while we now consider a lightning flash as something like the discharge of a condenser through its own dielectric, made up of excessively frequent alternations, say something like 300,000 times per second, the spark, or core of incandescent air, may seem to have had its beginning at the earth's surface. That is to say, the air gap breaks down first at a point near the earth.

13. Indifference of lightning to the path of least resistance. Nearly all treatises upon lightning up to within very recent times, assumed that lightning always followed the path of least resistance. "It is simply hopeless to pretend to be able," says Lodge, "to make the lightning conductor so much the easier path that all others are out of the question." The path will depend largely upon the character of the flash.

14. Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately, these are exceptional instances. The great majority of flashes in our latitudes are not so intense but that a good lightning rod, well

earthed, makes the most natural path for the flash. We have many instances, however (not to be confounded with cases of defective rods), where edifices, seemingly well protected, have been struck below the rods.

15. Paradox of paradoxes, a building may be seriously damaged by lightning *without having been struck at all*. Take the famous Hotel de Ville of Brussels. This building was so well protected that scientific men pronounced it the best protected building in the world against lightning. Yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunderstorm, some one flash started "surings" in a piece of metal not connected in any way with the protective train of metal. The building probably did not receive even a side flash. This is, therefore, a new source of danger from within, and but emphasizes the necessity of connecting metal with the rod system.

16. Lightning does sometimes strike twice in the same place. Whoever studies the effects of lightning's action, especially severe cases, is almost tempted to remark that there is often but little left for the lightning to strike again. No good reason is known why a place that has once been struck may not be struck again. There are many cases on record supporting the assertion.

17. As lightning often falls indiscriminately upon tree, rock, or building, it will make but little difference sometimes whether trees are higher than adjoining buildings.

18. It is not judicious to stand under trees during thunderstorms, in the doorway of barns, close to cattle, or near chimneys and fire places. On the other hand, there is not much sense in going to bed or trying to insulate one's self in feather beds. Small articles of steel, also, do not have the power to *attract* lightning, as it is popularly put, or determine the path of discharge.

19. Unnecessary alarm. Just in advance of thunderstorms, whether because of the varying electrical potential of the air, or of the changing conditions of temperature, humidity, and pressure, and failure of the nervous organization to respond quickly, or to whatever cause it may be due, it cannot be denied that there is much suffering from depression, etc., at these times. It is, perhaps, possible that these sufferings may be alleviated. Apart from this, many people suffer greatly from *alarm* during the prevalence of thunderstorms, somewhat unnecessarily, we think. Grant even that the lightning is going to strike close in your vicinity. There are many flashes that are of less intensity than we imagine, discharges that the human body could withstand without permanent serious effects. Voltaire's caustic witticism "that there are some great lords which it does not do to approach too closely, and lightning is one of these," needs a little revision in these days of high potential oscillatory currents. Indeed,

the other saying, "Heaven has more thunders to alarm than thunderbolts to punish," has just so much more point to it as it is nearer the truth. *One who lives to see the lightning flash* need not concern himself much about the possibility of personal injury from that flash.

20. Finally, if you should be in the vicinity of a person who has just been struck by lightning, no matter if the person struck appears to be dead, go to work at once and try to restore consciousness. There are many cases on record proving the wisdom of this course; and there is reason for believing that lightning often brings about suspended animation rather than somatic death. Try to stimulate the respiration and circulation. Do not cease in the effort to restore animation in less than one hour's time. For an excellent illustration of a case of severe lightning shock and recovery, due, it would seem, to prompt action by the medical gentlemen present, all who are interested may consult the "Medical News," August 11, 1888. A number of cases corroborative of this view are on record in various medical journals.

IV.—DIRECTIONS FOR PROCEDURE IN CASE OF APPARENT DEATH FROM LIGHTNING.

These directions are based upon Dr. Augustin H. Goelet's "How to Deal with Apparent Death from Electric Shock," reprinted by permission of "The Electrical World;" revised and modified for death from lightning, by Dr. W. F. R. Phillips, of the Weather Bureau. Dr. Goelet says:

An electric shock may produce death in one of two ways, viz: (1) By producing destructive tissue changes, when death is absolute, or (2) by producing sudden arrest of the respiratory and heart muscles through excitement of the nerve centers, when death is only apparent; in other words, animation is merely suspended. The subject may be aroused from this syncope if efforts at resuscitation are not too long delayed.

The alternating current, which is usually regarded as the most deadly, strange to say, nearly always produces death in this second manner.

To say that a person has received a shock from a wire conveying a current of four or five thousand volts does not necessarily signify that the body has been subjected to the full force of the current, even if the meter does register nearly one ampere during the time of the accident. In view of the fact that the human body offers a resistance of several thousand ohms, which resistance is greatly increased by imperfect contact and by charring and burning the tissues at the points of application, it is not often that the internal structures or vital organs are submitted to a very considerable volume of current, though it apparently passes through the body. It must be borne in mind that when the clothing is moist with perspiration or wet with rain it offers a circuit of less resistance than the human body, and in this event the body receives only a shunt current very much less in quantity than the main current. The bulk of current in this instance passes over the surface and does not enter the body. This may explain the survival of some who have apparently withstood very powerful currents.

It must be presumed, therefore, that electricity seldom kills outright, though the condition of suspended animation, which it induces, would result in death if not counteracted.

All things considered, it is rational to attempt the resuscitation of those apparently killed by electricity, and, if not too long delayed, the effort promises fair chances of success, provided proper means are instituted.

If the body has actually been submitted to a current of sufficient volume to produce destructive tissue changes, all efforts at resuscitation will of course be futile.

If, on the other hand, only respiration and the heart's action have been temporarily arrested, there is a condition of syncope simulating apparent death by drowning or from anesthetics, and the physician knows that patients in this condition are frequently revived. Laymen will appreciate the nature of this condition if it is explained as one of exaggerated faint, and would not feel appalled upon encountering it if previously instructed how to cope with it. In an ordinary fainting spell the necessity to stimulate is universally appreciated. In syncope resulting from an electric shock stimulation is likewise indicated, but more vigorous measures are required. This is the only difference.

As said above, the direction to treat one shocked by electricity as one drowned may be misleading, as the conception of the layman of the necessities in this case would be to roll the body on a barrel. Let him understand that the condition is one of exaggerated faint; prompt stimulants are necessary. *The man must be made to breathe*, if this is possible, and the efforts to induce respiration must not be suspended until breathing is fully and normally restored, or until it is absolutely certain that life is extinct. This can not be assured in less than an hour's persistent, energetic, tireless effort.

DIRECTIONS FOR ARTIFICIAL RESPIRATION.

The body must be placed upon the back. A roll made of a coat or anything else convenient (*rolled* not folded) is placed under the shoulders, and must be sufficiently large to so prop the spine up as to drop the head backward. The operator should kneel behind the subject's head, grasp the elbows and draw them well over the head, so as to bring them almost together above it and hold them there for two or three seconds. Then he carries them down to the sides and front of the chest, firmly compressing it by throwing his weight upon them. After two or three seconds the arms are again carried above the head and the same maneuver is repeated at the rate of fifteen or sixteen times per minute. At the same time the tongue must be drawn out to free the throat. This manipulation stimulates respiration in the following manner, viz: When the arms are extended over the head, the chest walls are expanded, just as in inspiration, and if the throat is clear the air will rush into the lungs. When the arms are brought down to the sides of the chest, compressing it, the air is expelled, just as in expiration. * * * The operator must, however, appreciate the fact that this manipulation must be executed with *methodical deliberation* just as described and never hurriedly nor half-heartedly. To grasp the arms and move them rapidly up and down like a pump handle is both absurd and absolutely useless. .

In addition to this, if an assistant be at hand, the tongue, held by a cloth or handkerchief to prevent slipping, should be seized and drawn forcibly out during the act of inspiration or when the arms are extended above the head, and when the chest is compressed it may be allowed to recede. The rythmical traction upon the tongue is in itself an excellent stimulant of respiration. It acts not only by freeing the throat of the tongue, which may fall back and obstruct breathing, but also by reflex irritation, through the frenum or bridle under the tongue being drawn forcibly against the lower teeth.

The procedure described and recommended by Dr. Goelet is that known as Sylvester's method. An equally efficacious method is that known as Howard's, which also keeps the passage through the windpipe free without the aid of an assistant, and is recommended for that reason. It is as follows:

Place the subject on his back, head down and bent backward, arms folded over the

head (under no conditions raise the head from the ground or floor). Place a hard roll of clothing beneath the chest with the shoulders declining slightly over it. Open the mouth, pull the tongue forward, and with a cloth wipe out saliva or mucus. Thoroughly loosen the clothing from the neck to the waist (but do not leave the subject's body exposed, for it is essential to keep the body warm). Kneel astride the subject's hips, with your hands well opened upon his chest, thumbs pointing toward each other and resting on the lower end of the breastbone; little fingers upon the margin of the ribs and the other fingers dipping into the spaces between the ribs. Place your elbows firmly against your hips, and using your knees as a pivot press upward and inward toward the heart and lungs, throwing your weight slowly forward for two or three seconds, until your face almost touches that of your patient, ending with a sharp push which helps to jerk you back to your first position. At the same time relax the pressure of your hands so that the ribs springing back to their original position will cause the air to rush into the subject's lungs. Pause for two or three seconds and then repeat these motions at the rate of about ten a minute until your patient breathes naturally, or until satisfied that life is extinct. If there is no response to your efforts persistently and tirelessly maintained for a full hour, you may assume that life is gone.

No matter which method for respiration is used, it is important to maintain the warmth of the body by the application of hot flannels, bottles of hot water, hot bricks, warm clothing taken from bystanders, etc.

Firmly and energetically rub the limbs upward so as to force the blood to the heart and brain. If an assistant is present let him attend to this. Remember above all things that nothing must interrupt your efforts to restore breathing.

When swallowing is established, a teaspoonful of warm water, wine, diluted whisky or brandy, or warm coffee should be given. Sleep should be encouraged. In brief:

1. Make the subject breathe by artificially imitating the respiratory movements of the chest.
2. Keep the body warm.
3. Send for a physician.

Of the visible effects of lightning stroke upon the human body little more can be said than that sometimes burns, usually superficial, have been noticed, frequently red lines or markings, which are localized congestions of the small blood vessels of the skin. These from their irregularities and branchings have led to the fanciful idea of photographs of trees, etc.

V.—EFFICIENCY OF CONDUCTORS.

A practical application of the efficiency of lightning conductors will now be considered. On June 5, 1885, the Washington Monument, at Washington, D. C., at that time the highest edifice in the world, was struck by lightning. The barograph curve (Fig. 6) shows the fluctuation in pressure about the time of the occurrence of the stroke, 3.15 p. m. The storm itself was, as usual, a secondary depression in the southeastern or southern quadrant of a "low" area, and at Washington resulted in a high forenoon temperature, with a maximum of

90° F. about noon, with fresh southerly winds, veering to southwest at noon; to northwest at 1.23 p. m.; to northeast at 1.40 p. m., and backing to northwest at 1.42 p. m.; to east at 2.20 p. m.; to northwest at 2.37 p. m., and veering to northeast at 2.40 p. m., whence it shifted to southwest at 3.02 p. m.; to northwest at 3.10 p. m., and at 7 p. m. was blowing steadily from the north. The first thunder was heard at 1.07 p. m., and rain began at 1.23, ceasing at 2 p. m., commencing again at 2.20 p. m., and ending at 3.05 p. m. Thunder continued at frequent intervals to 3.50 p. m. The rain was at times heavy, and hail fell in the northern part of the city. Amount of rainfall at Signal Office, 0.61 inch.

Colonel Casey, U. S. Army, the engineer in charge of the construction of the monument, requested Profs. Rowland, Newcomb, and Mendenhall to examine the part struck and suggest what precautions should be taken to ensure the safety of the monument. It is proper to remark that the monument had been for all practical purposes finished and had already experienced storms of seemingly greater violence.

From the letter¹ of the commissioners charged with the completion of the monument, we find that "a considerable amount of unexpected work" was performed in the erection of rods and points to protect the obelisk from lightning. "The lightning protectors as established for the monument were commenced in January, 1880, and were finished in January, 1885," practically the date of completion of the monument. The elevation of the solid aluminium pyramid (which weighs 100 ounces and is 8.9 inches high and 5.6 inches square at base, with angle at the vertex of 34° 48') is 555 feet (169.16 meters).

The conductors consist of the four hollow wrought-iron Phoenix columns, supporting the elevator machinery. The bottoms of these four columns rest upon and are bolted to cast-iron shoes, standing upon the floor of the large drum pit, * * * and the shoes are connected to $\frac{3}{4}$ -inch soft copper rods, led to the bottom of a well in the center of the foundation. This well is 32 feet 10 inches in depth below the bottom of the drum pit and 15 feet 8 inches below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches above its bottom. After the copper rods were inserted the well was filled up with clean sharp sand for a depth of 15 feet 8 inches, or up to the level of the bottom of the old rubble-stone foundation of the monument. These four columns so arranged at their bases, *and always projecting above the top of the shaft, were continually lengthened as the building of the shaft progressed, and for the five summers during which the masonry was in progress acted as the lightning conductors of the edifice.*² No disruptive discharge of electricity was experienced during those years." When the marble pyramidion

¹ Senate Ex. Doc. No. 6, 49th Congress, 1st session.

² Italics mine.

was completed, December, 1884, these four columns were within this marble covering, and from the extremity of each column a copper rod $\frac{3}{4}$ inch in diameter was run to the top stone and there united in a copper rod $1\frac{1}{4}$ inches in thickness, which passed vertically through the cap stone and was screwed into the solid aluminium pyramid.

The conductors "when tested, gave an electrical resistance of 0.1 ohm from the tip of the terminal to the copper rods at the base, and 2.2 ohms for the ground connections, making a total resistance of 2.3 ohms for the conductor. The system was entirely completed and connected on January 20, 1885."

On April 5, 1885, during the passage of a heavy thundercloud over the monument, at least five immense sparks or bolts of electrical light were seen within a period of twenty minutes to flash between the terminals and the cloud without audible sound to the observers. A careful examination of the conductors and shaft after this phenomenon failed to reveal any effects from these discharges.

On June 5, however, during the thunderstorm described above, a disruptive discharge was seen to pass between the summit of the pyramidion and the cloud. Upon examining the structure a crack was discovered in the stone on the north face of the pyramidion just under the top stone, extending through the block in a line nearly parallel to the northeast corner and about $8\frac{1}{4}$ inches from it. (Fig. 5.) The fragment was pressed outward about $\frac{3}{4}$ inch at its bottom, chipping a small piece off the lower corner of the top stone into which it was locked, and was easily forced back to place and bolted to the solid stone from which it had been torn.

The recommendations of the gentlemen above named, who were asked to make a careful examination, were, in short, that the interior conductors should be connected "with a system of rods and a greater number of points, to be located upon the exterior of the pyramidion." Four $\frac{1}{4}$ -inch copper rods were fastened by a band to the aluminium terminal and led down the corners to the base of the pyramidion, and then through the masonry to the columns.

"As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods $\frac{1}{2}$ and $\frac{3}{4}$ inch in diameter, respectively, furnishing 16 rods in all, connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the 11 highest horizontal joints of the masonry of the pyramidion they are connected to each other all around by the other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all."

Eight years have now passed since the alterations were made and the monument stands uninjured. Unquestionably, standing as it does, 555 feet high, in the center of flat, well-watered ground, it constitutes a most dangerous *exposure* for lightning flashes. No better illustration of the value of lightning conductors can be asked.

VI.—PROTECTION OF BARNS BEFORE AND AFTER HARVEST.

The question is sometimes asked "Are thunderstorms more destructive to barns after harvest than before?" The following reasons have been advanced as favoring an affirmative answer.

1. Before harvest the stalks of the growing grains and grasses, with their many points and heads, act as conductors of electricity, and serve as discharging points, to some degree neutralizing the electric stress in the air. After harvest the fields are more or less bare and the electric tension must be relieved through buildings and prominent features in the landscape.

2. The barn filled with crops is warmer than one that is empty, and is also more inflammable; if struck by lightning, it is more likely to be destroyed by fire. Packed hay, for example, naturally makes a barn or stable warmer than its surroundings, and with the warmth there is more or less moisture. Uprising warm currents of air probably form which, while not strong ordinarily, may be accentuated during thunderstorms, and play a significant part in determining the line of discharge. And, finally, barns, as a rule, are located on hills or hillsides, in positions to experience the maximum effects of currents due to heating or topography.

Before using the statistics given below it should be said that the farmer and the whole community notice the destruction of a barn filled with the produce of a year, more than they would notice the loss of an empty barn. Hence, some cases of empty barns have probably been passed over as hardly deserving notice, while all the cases of stocked barns have probably been reported.

The Weather Bureau statistics for 1894 show that, previous to August 1, 130 barns were struck, with a loss of \$134,000. After August 1, 138 barns were struck, with a loss of \$273,500.

Comparing these with persons killed, churches and dwellings struck, we have—

Before August 1, 223 persons killed, 173 dwelling, 40 churches.

After August 1, 113 persons killed, 87 dwellings, 15 churches.

It therefore appears that a barn is more liable to be struck when filled with crops than when empty.

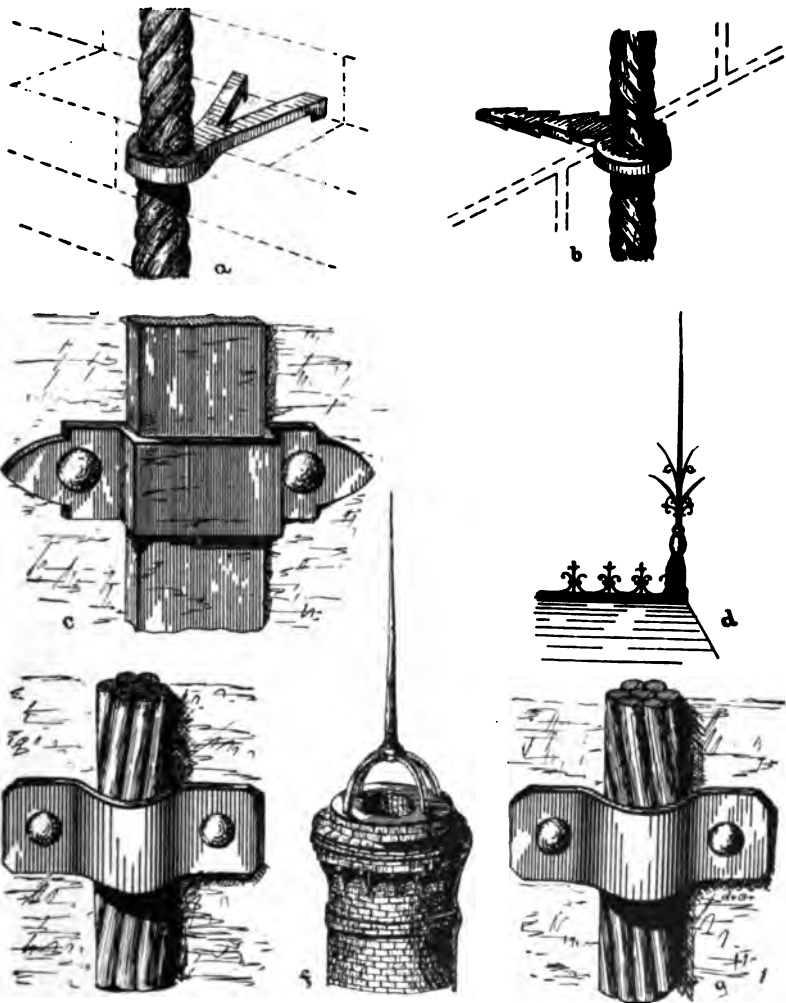


Fig. 1. Conductors and fastenings. From Anderson, and Lightning Rod Conference Report.





Fig. 2. Chinnney, struck July 29, 1890. From *Elec. Zeits.*, Grebel.





Fig. 8. Washington Monument, struck June 5, 1885.

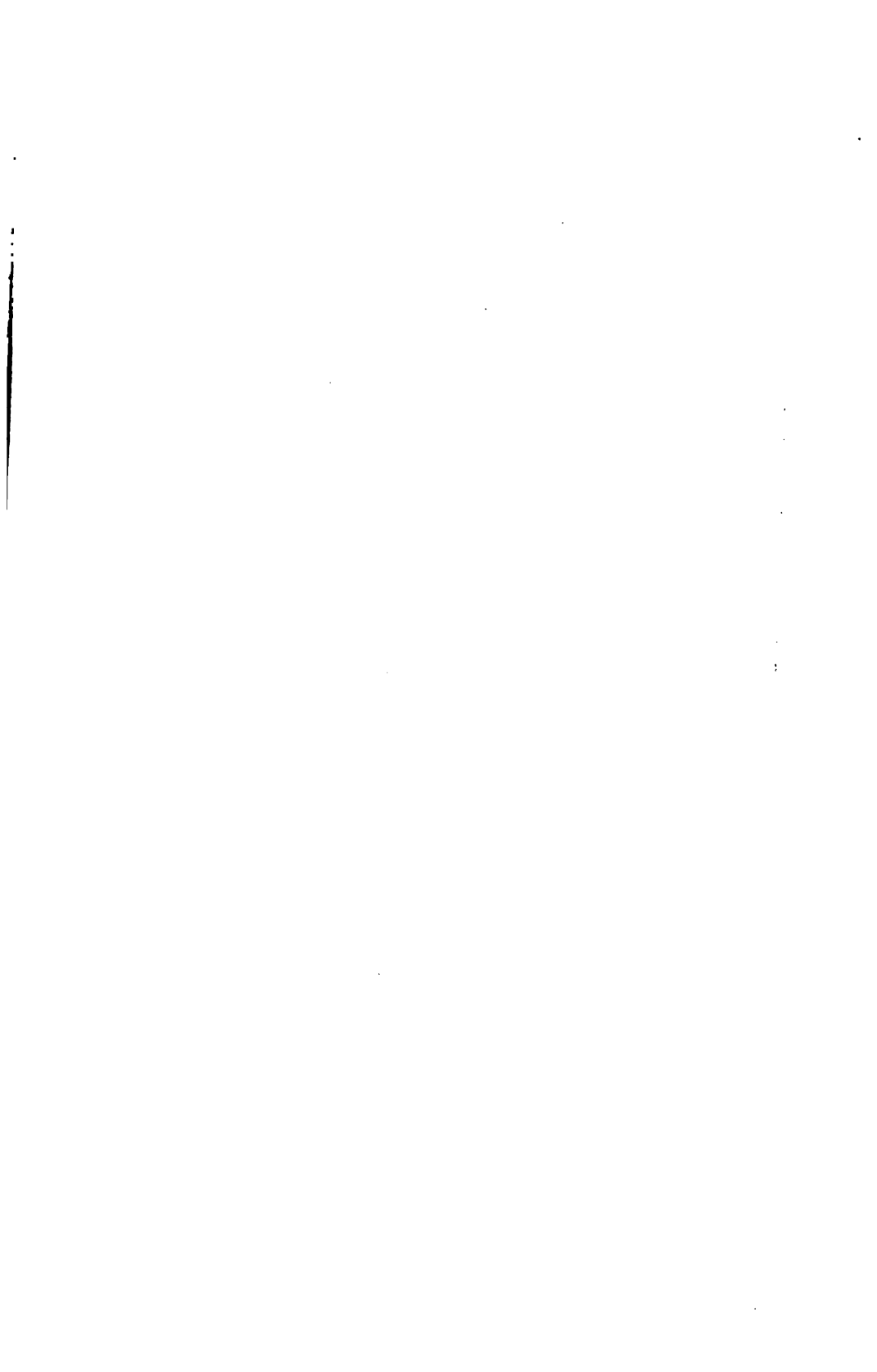
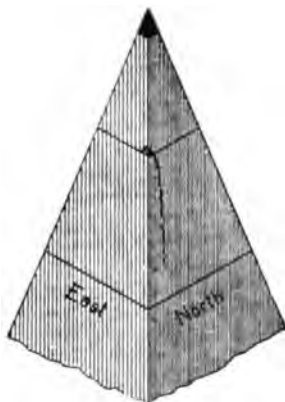




Fig. 4. Rod melted by lightning.
From Franklin's Works.



◆ Aluminium tip weighing 100 lbs.
Nearly 9" high 5½" square at base.
Height from ground 555 ft. (169 metres)

Struck April 5th 1885 without damage
June 5th .. crack on North
face just under top stone, extend-
ing through the block in a line
nearly parallel to NE corner.

Fig. 5. Aluminium tip of Washington Monument.

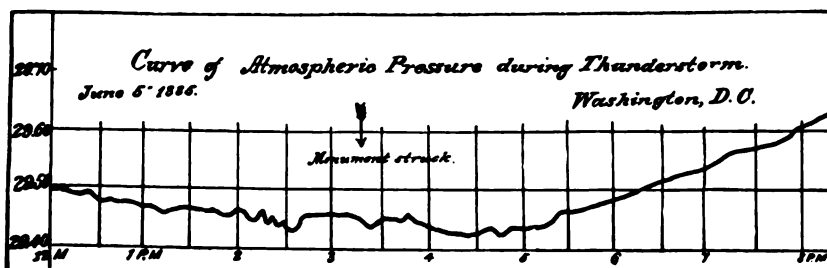


Fig. 6. Curve of barometric pressure.

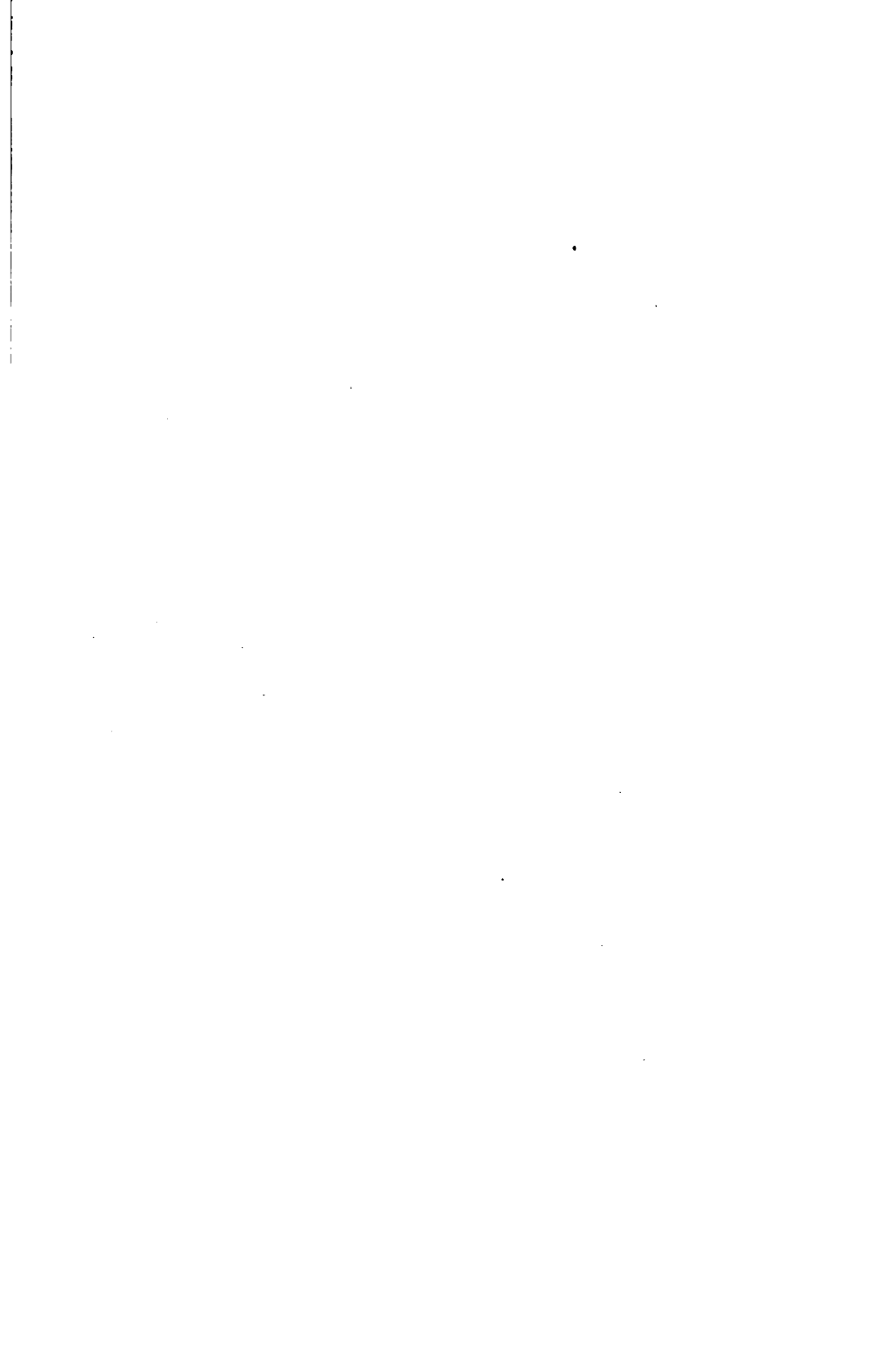




Fig. 7. Multiple flash. From "Pop. Sci. Monthly," 1898, McAdie.



Fig. 8. Destructive flash. From photograph by McAdie.

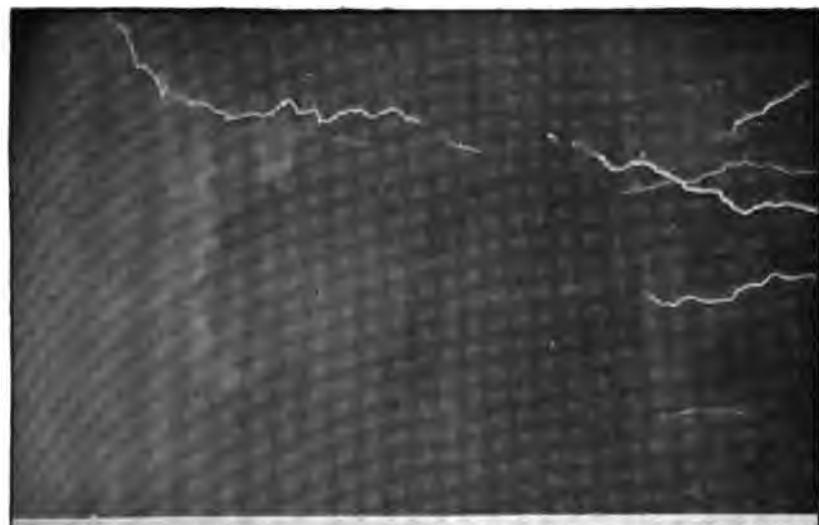
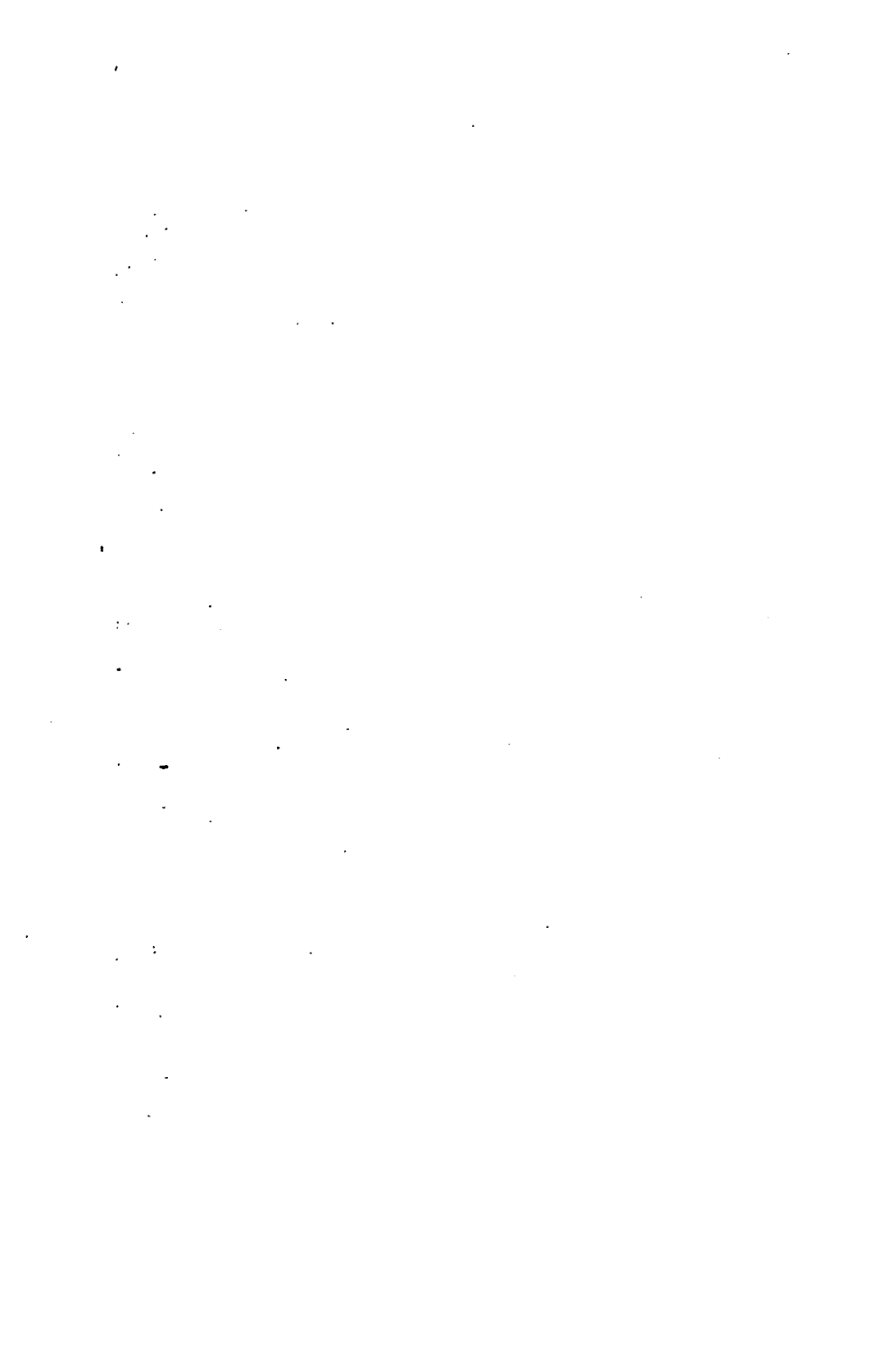


Fig. 9. Cloud and multiple flash. From photograph by McAdie.



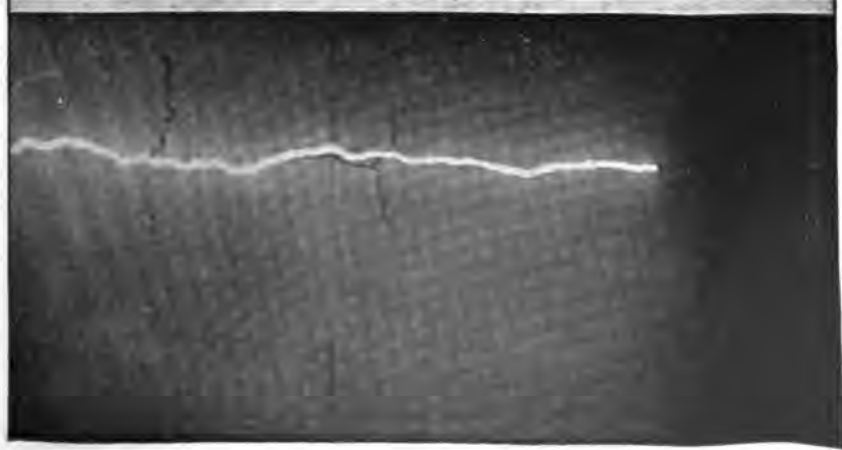
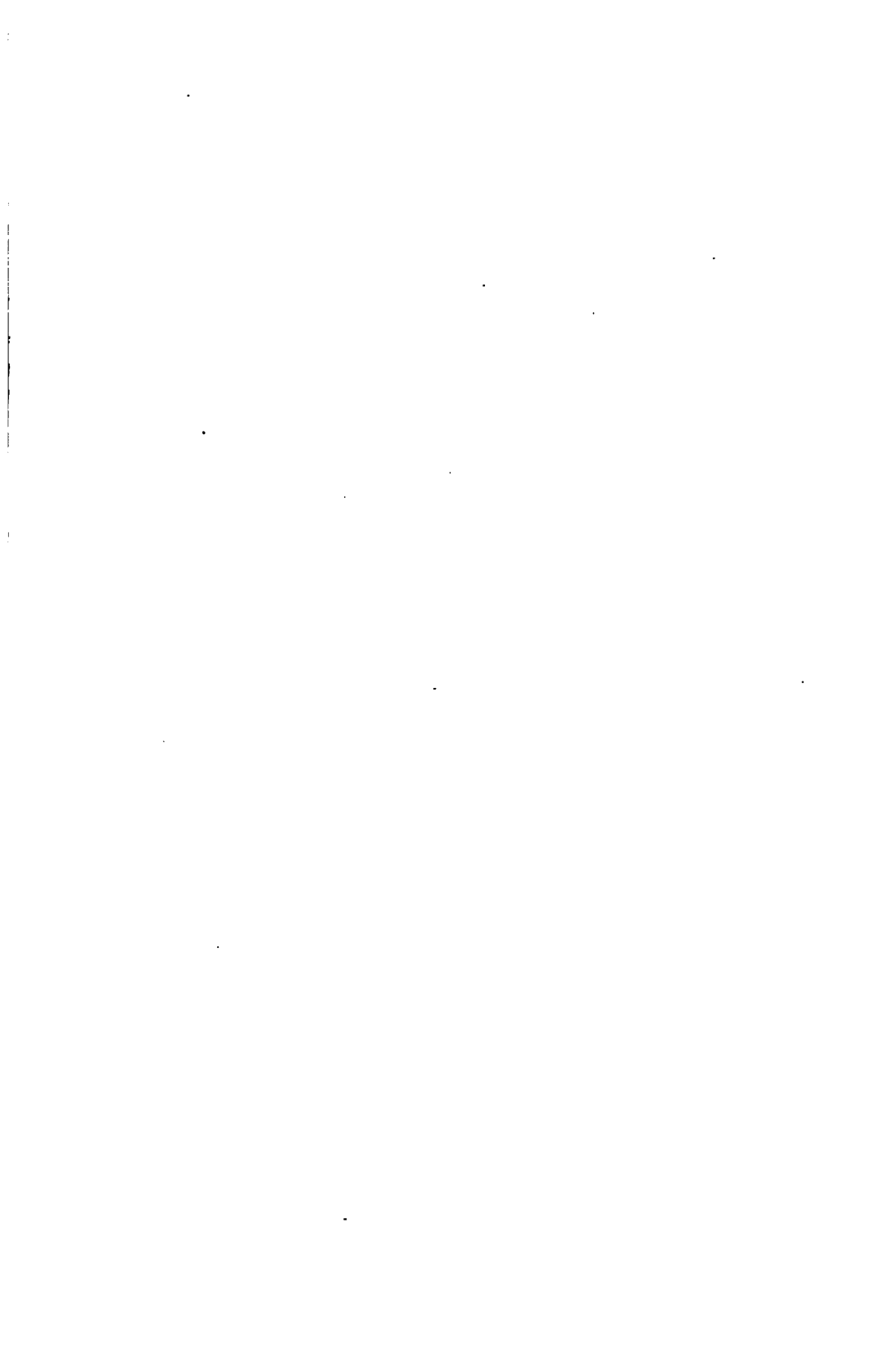


Fig. 10. Impulsive rush and so-called dark flashes.
From "Pop. Sci. Monthly," McAdie.



Fig. 11. Multiple flash. From "Scribner's Mag.," A. Binden.



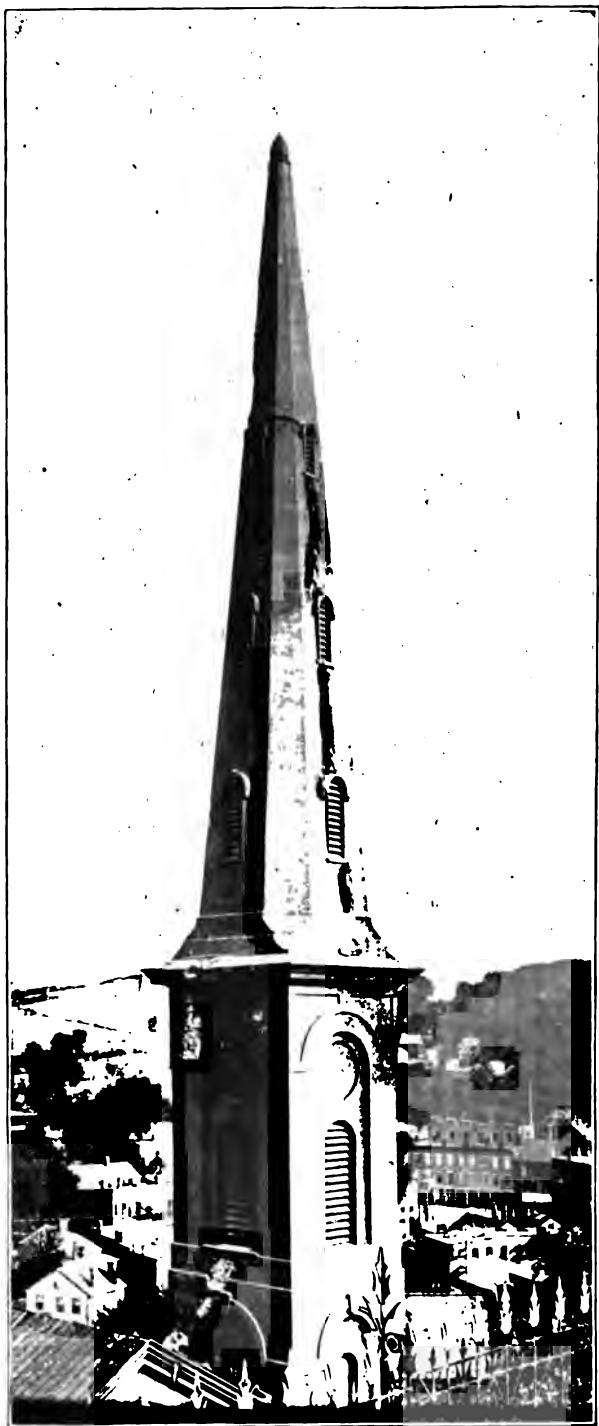


Fig. 12. Spire (198 feet, brick and brownstone) struck July 29, 1894.
From "Scientific American," F. J. Moulton.

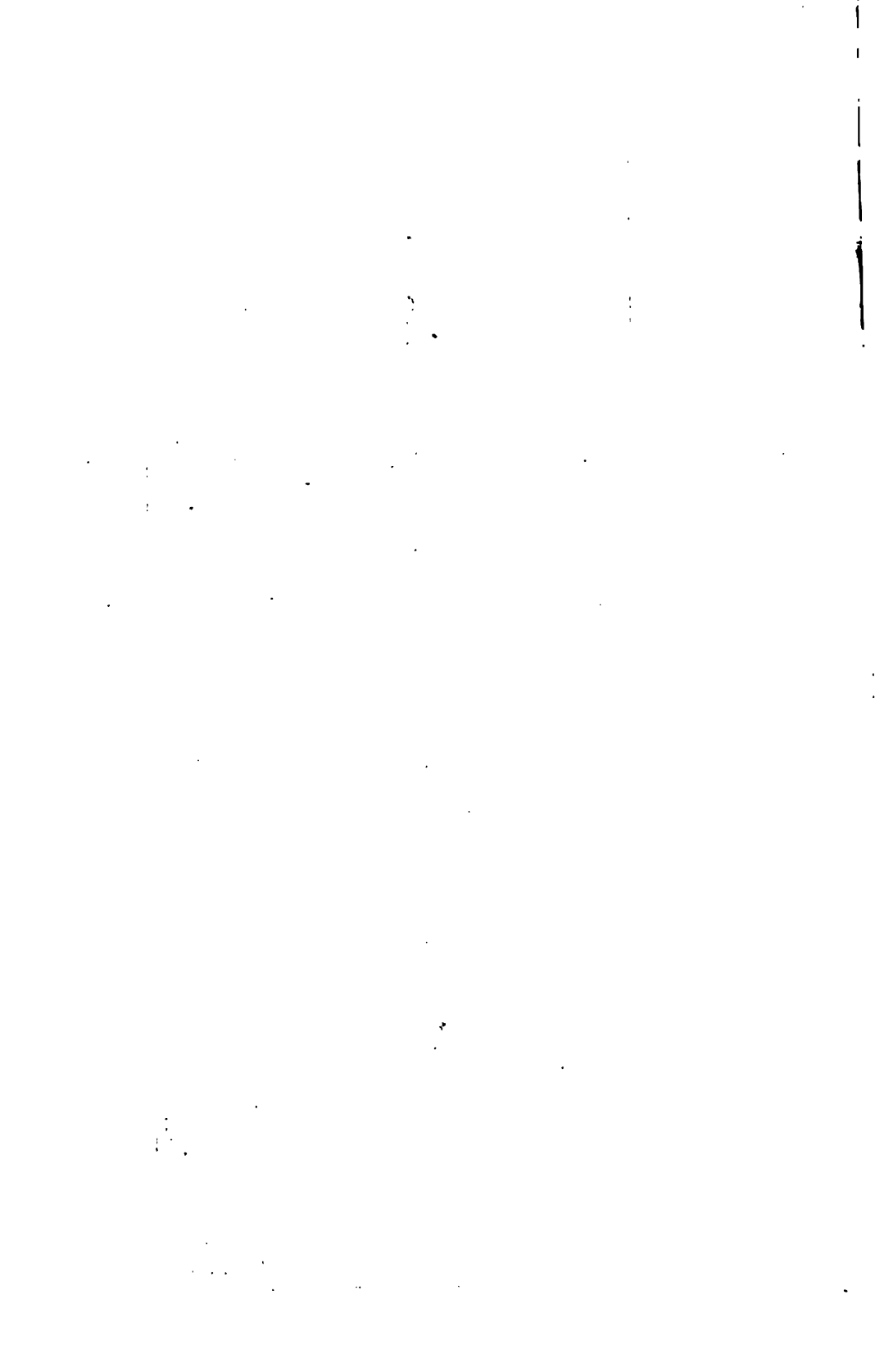




Fig. 13. Burr oak shattered by lightning March 15, 1894. From "Scientific American," Frank Woodmaney.

Bulletin No. 16.—W. B., No. 77.

Price 15 cents.

From U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

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BY MEANS OF THE
ABSORPTION LINES OF THE SPECTRUM.

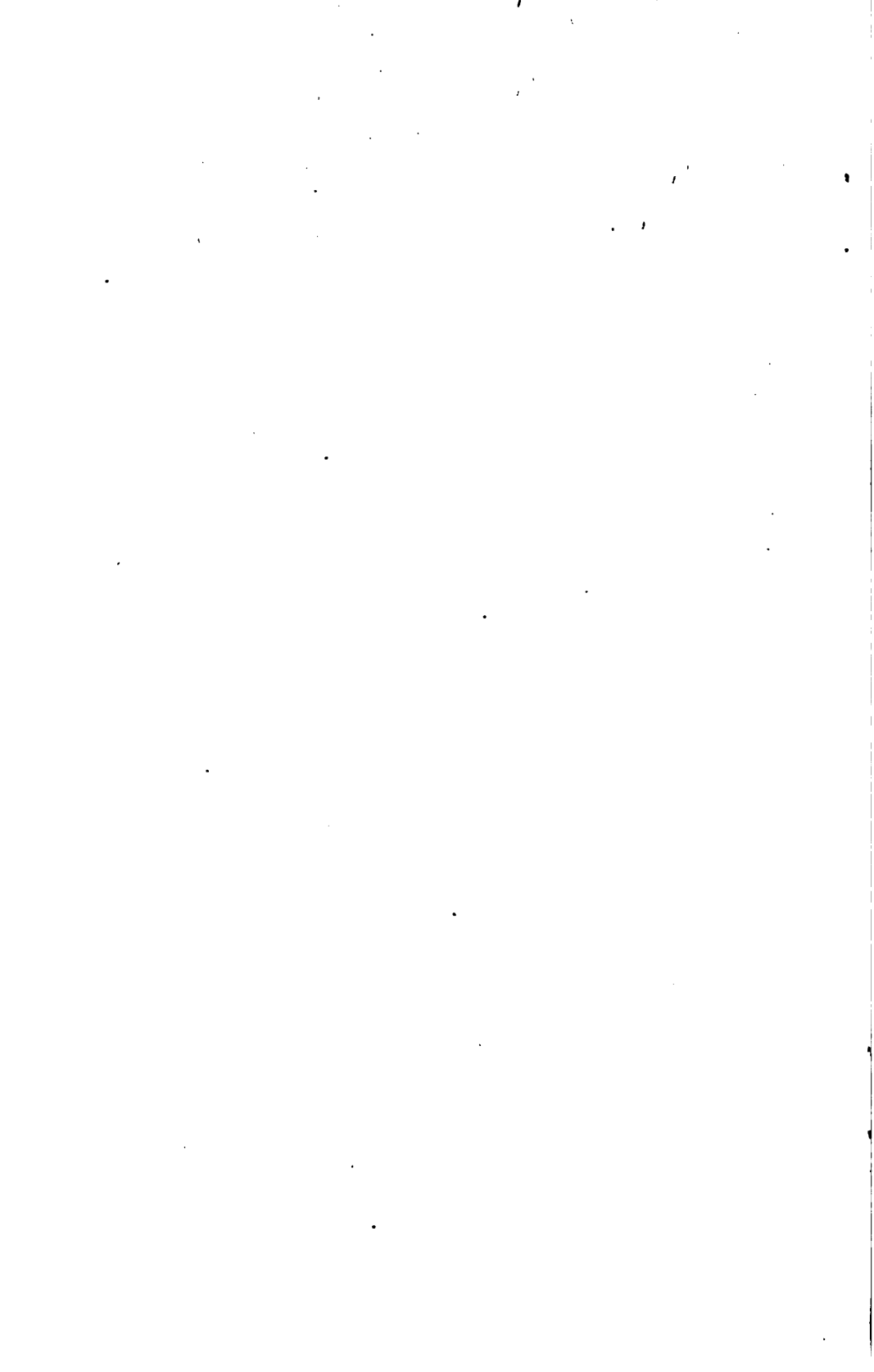
BY

L. E. JEWELL,

UNDER THE GENERAL SUPERVISION OF
PROF. H. A. ROWLAND,
OF JOHNS HOPKINS UNIVERSITY.



WASHINGTON:
WEATHER BUREAU.
1896.



LETTER OF TRANSMITTAL.

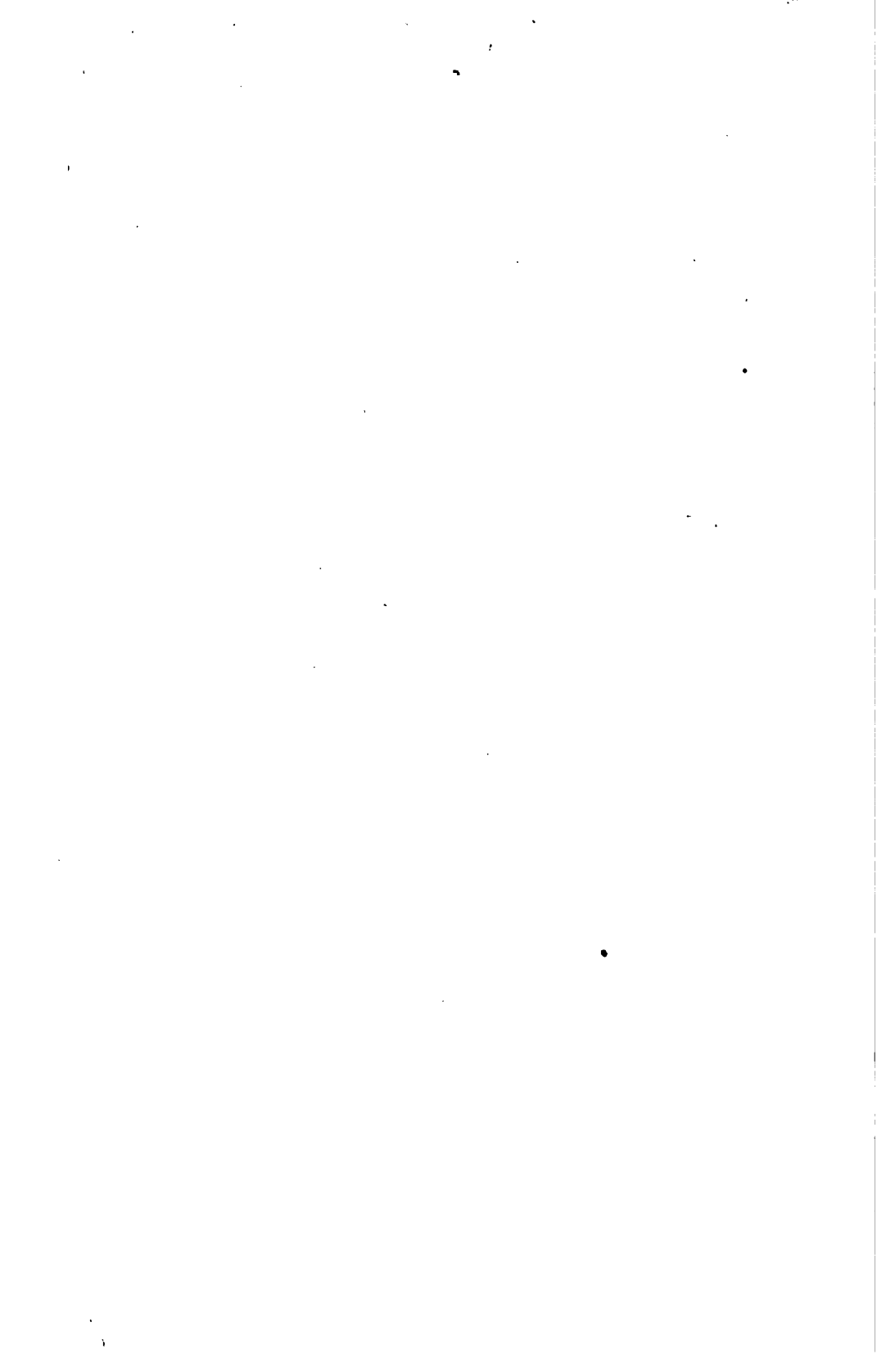
U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., September 21, 1895.

SIR: I have the honor to transmit herewith a paper entitled "The Determination of the Relative Quantities of Aqueous Vapor in the Atmosphere by means of the Absorption Lines of the Spectrum." This has been prepared by Mr. L. E. Jewell, under the general supervision of Prof. Henry A. Rowland, of Johns Hopkins University, Baltimore, Md., and its publication as Weather Bureau Bulletin No. 16 is recommended.

Very respectfully,

WILLIS L. MOORE,
Chief.

HON. J. STERLING MORTON,
Secretary.



THE DETERMINATION OF THE RELATIVE QUANTITIES OF AQUEOUS VAPOR IN THE ATMOSPHERE BY MEANS OF THE ABSORPTION LINES OF THE SPECTRUM.

By L. E. JEWELL.

The investigation upon which the present report is based was begun by me, in accordance with the recommendation of Prof. Henry A. Rowland, January 16, 1892.

In my preliminary report of June, 1892, I expressed the belief that much more satisfactory results would be obtained if the investigation of the "rain band," which had then been carried on for about six months, were continued so as to include results for a whole year.

This has been done, and I now have observations from January 16, 1892, to July 31, 1893, inclusive. Those for the latter part of July and during the months of August and September, 1892, were made by Dr. C. P. Cronk and G. N. Wilson of the Baltimore station, U. S. Weather Bureau, to whom I am much indebted.

This report includes the results obtained for the period from January 16, 1892, to January 31, 1893; the observations from the latter date to July 31, 1893, not being as yet reduced.

Observations were made both by eye and by photographic means, but the latter method was soon discontinued as unsuitable for the purpose and dependence placed upon eye observations alone.

A photographic map of that portion of the solar spectrum from wave lengths 5880 to 5950 was used for selecting a suitable series of solar and water-vapor lines for purposes of comparison (see Fig. 1). The study was confined to this region because there were no entirely suitable photographs at hand of the rest of the rain band, though there are a number of lines in the rest of the band that would be of value in intensity comparisons, as also would be the series of water-vapor lines in the neighborhood of the hydrogen line "C."

The method of observation used was to estimate the intensity of a water-vapor line in terms of the solar line most nearly equal to it in intensity, and in close enough proximity to render the comparison easy and sufficiently exact. One observation generally included several comparisons.

A more exact method would have been to make the observation when such a pair of lines (one solar and one water vapor) were of equal intensity, as the eye is very reliable for such comparisons, but

much less so in estimating differences of intensity. This, however, was impracticable under the circumstances, both because of the greater length of time it would require for observations, and because it would make necessary a more extensive series of comparison lines than had been selected in the region of the spectrum to which I had limited the work.

Having selected a series of comparison lines, it became necessary to determine the relative intensities of both the solar and the water-vapor lines used in the comparisons, in order that the observations might be available for actual measurements of intensity and might mean something really definite instead of mere guesswork. For this purpose a photographic scale was constructed, consisting of a series of lines regularly increasing in intensity from a line barely visible to others as strong as were desired.

A large, narrow slit was used, with a gaslight behind it and a plate of ground glass between them, to produce a more even light. A series of images of the slit were then made upon a photographic plate held in a camera, the lens of which had been covered with a piece of wire gauze, fine enough to produce a shading to the edge of the lines and a somewhat diffuse appearance of the lines themselves, but not sufficiently fine to produce any definite side lines due to diffraction fringes.

In the scale thus constructed the exposures were so timed as to be in geometrical ratio, the object being to form a scale of lines whose intensity should vary, as the geometrical series 1, 2, 4, 8, 16, etc. These lines formed the principal divisions, while, to facilitate measurements, an intermediate line was added by making the ratio of the series 1.414 or $\sqrt{2}$.

A fine-grained plate was used and so developed as to secure the best gradation and the clearest background obtainable. In this way a scale was produced, the lines of which closely resembled those in the spectrum of the earth's atmosphere and the better class of lines in the solar spectrum. The scale answered very well for preliminary work, but has several defects, which would be objectionable in more refined work. It is, however, possible to produce a photographic scale which will be entirely satisfactory. It is not true that a series of lines thus produced vary in intensity exactly as a geometrical series, but this is approximately true, and consequently such a scale possesses some of the advantages of a table of logarithms. By its use variations in the spectrum as a whole, such as are caused by the use of different gratings and different orders of spectra, with more or less diffuse light and different widths of slit, can be expressed by a constant, by the application of which observations made with different gratings under different circumstances can be reduced to standard conditions. This was shown experimentally, during the progress of

this investigation, by the fact that measurements made in both the first and second order spectra of the grating used differed by a constant, and measurements of the different lines of the oxygen bands differed by constants, irrespective of the elevation of the sun and the order of spectra or width of slit used. As a consequence of the properties of such a scale all necessary computations and reductions can be greatly simplified and shortened. The observations included in the scope of this paper have only been partly thus reduced, though had the method been extended much labor and time might have been saved.

In measuring the intensities of the solar lines the scale was held in one hand and an eyepiece in the other, and the lines of the scale brought into focus with the solar line to be measured, the latter being brought into position between the two lines of the scale most nearly of the same intensity as the line to be measured. Holding the scale in the hand is not an ideal way of measuring and is not to be recommended, but it answered the purpose of a preliminary set of measurements, and there was no other convenient arrangement available. The relative intensities of the water-vapor lines should have been measured in this way, making several determinations with different degrees of humidity of the air, but this was not done, partly because of the lack of time required for making such measurements and partly because, under the conditions prevailing in Baltimore when the measurements were made, the conditions, otherwise favorable, occurred when the sun was nearing the horizon and the intensities of the lines were changing too rapidly. Under these circumstances a much less desirable plan was adopted, viz, that of selecting those observations which included a comparison of both the lines to be measured and of the line taken as a standard (I_s) with solar lines, plotting the values thus obtained and deriving in this manner the relative values of the various water-vapor lines selected in terms of the one taken as standard. This plan is not to be recommended, but was the only one that seemed to be available.

In the same way the relation of eye estimates of differences in intensity to scale values was determined by thus selecting observations which were considered most suitable for the purpose. The results were plotted and a curve drawn representing the relation of eye estimates to scale values, and by which the differences in intensity as estimated by the eye were reduced to scale values, when the lines compared were not of equal intensity. This determination was not altogether satisfactory, but answered fairly well, as lines were generally selected for comparison which differed but little in intensity.

In Table II are given the intensities of the solar lines used in terms of the standard line selected (Q) with their approximate wave lengths.

In Table III are given the water-vapor lines used, with their intensities in terms of the line selected as standard (1_1) and their approximate wave lengths.

These values are not so accurate as might be desired, and are known to contain some errors, but on the whole they are fairly well determined, and I do not think it would be worth while to make a redetermination by the same method.

Considerable trouble was occasioned by a few of the lines being partly solar and partly water vapor, necessitating special observations to determine how much of the total intensity was due to each source.

Unfortunately, one of the most useful lines, and the one most used for low sun observations, was found to be of this character. It is a double solar line at wave length 5914.384, and has a water-vapor component coincident with the red component of the double.

Having finished the determination of the relative intensities of the lines selected and completed a series of observations, the results were put in tabular form and the reductions made as follows: The table (I) begins with the date of the observation in the first column; then follows what may be called the astronomical data, viz, the time (T) according to "eastern standard" time; the hour angle (t), plus values representing values west of the meridian and minus values those to the east; the amplitude (A), reckoned from the south point, the signs being the same as for the hour angles; the apparent zenith distance (z), the correction for refraction having been made.

Then follows the amount (a) of atmosphere passed through by the sunlight at the given angle, and in the next column is given the factor (β) for reducing the intensities of the water-vapor lines as observed to what they would be were the sun in the zenith. This factor is only approximate and varies according to the season, but only the mean value for each month is used.

Then follow the original observations upon the various water-vapor lines, given in terms of the solar line with which they were compared.

The next series of columns give these values so reduced as to represent the intensity of the lines observed in terms of the standard solar line (Q).

In the next series of columns are the respective resulting values of the intensity of the standard water-vapor line (1_1) in terms of the standard solar line (Q).

Next is the column of means and then the reduced means, giving the means multiplied by the reduction factor (β). This represents the value of the means reduced to what they would be were the sun in the zenith.

Then follow the meteorological data, viz, the absolute humidity (h)

Date.	Time. <i>T</i>	Standard water-vapor					Meteorologic conditions.					
		ne (<i>l</i> ₁).			Resulting intensities (<i>l</i> ₂).		Absolute humidity.	Dew-point.	Relative humidity.	Temperature.	Pressure.	Rainfall.
		<i>g</i>	<i>h</i> ₁	<i>o</i> ₁	Mean. <i>m</i> .	Reduced mean. <i>β m</i> .						
1892. Jan. 16	8.00 a.						<i>G.p.c.f.</i> 0.967	°F. 18	% 76	°F. 19.0	Inches. 30.550	Inches. 0.00
	4.00 p.	0.630			0.630	0.156						
	4.10 p.			0.695	0.695	0.158						
	4.30 p.		0.960		1.000	0.173						
	4.50 p.			1.760	1.760	0.215						
	8.00 p.						1.208	20	87	23.0	30.33	0.00
1892. June 20	8.00 a.	<i>l</i> ₂	<i>o</i> ₁	<i>p</i> ₁			7.498	68	73	78.3	29.839	0.88
	12.35 p.	0.859	0.730		0.830	0.736						
	3.40 p.	1.042	0.910	0.960	1.000	0.519						
	5.15 p.	1.930	0.900		1.600	0.491						
	8.00 p.						8.521	72	79	79.0	29.769	Trace.
1903. Jan. 31	8.00 a.	<i>o</i> ₁	<i>p</i> ₁				1.745	27	70	35.6	30.245	Trace.
	9.45 a.		0.575		0.574	0.251						
	12.30 p.				0.370	0.209						
	3.00 p.		0.560		0.525	0.226						
	4.57 p.	1.330			1.860	0.266						
	8.00 p.						1.892	29	75	35.0	30.225	0.00

hat for purely atmospheric lines.

or the amount of water vapor contained in the air at the Baltimore station, given in grains per cubic foot; the dew point (*D. P.*); the relative humidity (*R. H.*); the temperature of the air (*t*); the height of the barometer (*b*), corrected and reduced to sea level; the precipitation (*p*) for the preceding twelve hours.

For comparison with meteorological data, the midday observation is much the most valuable, as the reduction to standard conditions (the conditions that would prevail were the sun in the zenith) is less liable to error. Consequently pains were taken to secure as complete a set of midday observations as possible. In addition to these a set of observations at various altitudes of the sun from noon to sunset were made every few days, in order that satisfactory curves for reducing observations to standard conditions might be constructed.

Considerable attention was also given to observations made upon the approach of both general and local storms and during the approach and prevalence of "cold waves." Observations were not confined to the water-vapor lines, but were occasionally made upon the various lines of oxygen, as it was desired to find the curve representing similar series of observations for one of the least changeable gases of the atmosphere. For this purpose oxygen lines were observed in the same manner as were the water-vapor lines, and, in addition, they were measured frequently by the scale, and the two methods were found to give the same results.

The observations were reduced and plotted and curves drawn representing approximately the mean monthly results. These monthly curves were used to reduce the observations to standard conditions. The daily curves differed considerably during the month, especially during spring and fall, but it was considered best for this investigation to only use a monthly mean curve.

In Table IV the intensity of the standard water-vapor line at various altitudes of the sun, during the different months of the year, is given as taken from the mean monthly curves referred to. In addition are given the intensities representing specially interesting conditions, viz, the readings from the curve of January 10, 1893, representing the curve for a "cold wave," and also the mean of the curves for July 14, 15, 16, 17, and 18, 1893, during the prevalence of warm, humid, weather conditions. In the same table are also given the results for oxygen. As this varies scarcely any during the year, a single curve suffices to represent it. The intensities given under oxygen are those of the first line in the tail of α (i. e., the oxygen line α), in terms of the same standard solar line (Q) used for comparison with the water-vapor line.

A study of the values of the intensity curves, as given in Table IV, brings out some interesting results. Not only are the intensities for the summer months much greater than for the winter months, but

the forms of the curves, or their slopes, are quite different and also decidedly different from the form of the curve representing oxygen, showing that the character of the distribution of water vapor in our atmosphere is greatly different from that of oxygen and also greatly different at different seasons.

An interesting fact is the similarity in the curves for December, January, February, and March; the rapid change in the curves during April and the beginning of May; the gradual changes after August and during the fall months. The most remarkable difference, however, is between the conditions prevailing during cold waves and very warm, humid weather. The distribution of water-vapor during cold waves seems to be much like that of oxygen, while during warm, humid weather it is almost entirely different.

In Table IV the values given in parentheses are somewhat uncertain, observations not having been made at these altitudes; the horizon as seen from the heliostat of the spectroscope is clear only during part of the spring and winter, and the highest altitude of the sun is at a considerable distance from the zenith during the winter.

As to the usefulness of the spectroscope in meteorological observations, my opinion is that for the study of the distribution of water vapor in the atmosphere it is of great value, but as an instrument for regular observations upon which are to be based the predictions of future weather conditions, it is not much of an addition to the instruments already in use. It might be of considerable use at times, but hardly sufficient to justify its use at most meteorological stations. However, if a few selected stations were equipped with a simple form of instrument of sufficient dispersive power valuable data might be secured.

The increase in intensity of the water-vapor lines is quite decided upon the approach of a general storm, and depends to some extent upon the direction and the azimuth of the sun, or the direction in which the instrument is pointed in relation to the position of the storm. There is much less of a change at the approach of a local storm, and if it be a small unimportant one, the strength of the water-vapor lines may scarcely be affected at all. Neither is there any perceptible increase in the intensity of these lines when the sun is shining through clouds, or when the sunlight passes immediately underneath even a fairly large cumulus cloud. However, there is likely to be a marked diminution in the intensity of the water-vapor lines immediately after, even a small local storm, with an increase again to what it was before if the storm has been an unimportant one.

It may also be of interest to note the fact that there is a difference in the curves representing morning and afternoon observations, especially during the colder part of the year, the slopes of the morning curve being steeper, and showing relatively less water vapor in the

lower regions of the air than during the afternoon. In my opinion observations made with small spectroscopes having insufficient dispersion to easily see the various lines distinctly, are worse than useless, as the region of the rain-band contains many solar lines which can not be distinguished from water-vapor lines without good definition and considerable dispersion.

The pointing of a spectroscope toward the sky, instead of the sun, will also give erroneous results of scarcely any use whatever for purposes of study.

 TABLE II.—*Solar lines.*

Name of line.	Intensity, $Q=1$.	Wave length.	Name of line.	Intensity, $Q=1$.	Wave length.
D ₂	4.250	5890.182	L	0.551	5916.475
A*	*	5891.4	M	0.211	5918.7
B	0.073	5892.0	N	0.288	5922.2
C	0.188	5892.9	O	0.488	5925.0
D	0.755	5898.066	P	0.891	5929.9
E	0.060	5898.4	Q	1.000	5930.410
D ₁	3.145	5896.154	R ¹	0.132	5933.9
F	0.330	5899.5	R	0.781	5934.883
G	0.146	5899.7	S	0.135	5941.9
H	0.197	5902.7	T	0.985	5948.781
I	0.611	5906.895	U	0.355	5949.5
I ¹	0.219	5907.1	V	0.680	5952.9
J	0.355	5910.1	W	0.319	5953.8
K*	*	5914.384	X	0.571	5956.925

* Intensities of solar lines having atmospheric components:

$$A = 0.215 Q + 0.135 I,$$

$$K = 1.28 Q + 0.375 I,$$

 TABLE III.—*Water-vapor lines.*

Name of line.	Intensity, $I_2=1$.	Wave length.	Name of line.	Intensity, $I_2=1$.	Wave length.
a ₁	0.235	5891.7	k ₄	0.205	5916.8
a ₂	0.700	5891.8	l ₁	0.425	5918.6
a ₃	*	5892.6	l ₂	1.000	5919.855
b ₁	0.300	5898.2	l ₃	0.418	5920.7
b ₂	0.355	5898.7	m	0.500	5923.7
c ₁	0.250	5894.6	n ₁	0.769	5924.4
c ₂	0.270	5895.1	n ₂	0.535	5925.1
c ₃	0.200	5895.3	o ₁	0.590	5925.4
d ₁	*	5896.395	o ₂	0.132	5929.4
d ₂	0.470	5899.1	o ₃	0.065	5929.6
e _{1,2}	0.980	.....	p ₂	0.117	5930.8
e ₁	0.410	5900.1	p ₃	0.125	5931.1
e ₂	0.620	5900.2	p ₁	0.800	5932.2
f ₁	*	5901.681	q	0.400	5932.9
f ₂	0.300	5902.3	r ₂	0.135	5935.4
g	0.570	5909.1	r ₁	0.295	5936.0
h ₁	0.355	5910.3	s ₁	0.550	5941.8
h ₂	0.500	5910.9	s ₂	.....	5942.6
j	0.485	5913.1	s ₃	.....	5942.8
k ₁	0.250	5915.1	t	.....	5945.4
k ₂	0.280	5915.6	u	0.635	5949.5
k ₃	0.225	5915.8			

* Intensities of water vapor lines having solar components:

$$a_3 = 0.070 Q + 0.410 I,$$

$$d_1 = 0.030 Q + 0.840 I,$$

$$f_1 = 0.050 Q + 0.950 I,$$

TABLE IV.—*Mean intensity from curves representing the mean value of βm for the respective months.*

Zenith distance.	1892.							
	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.
0°	(0.160)	(0.190)	(0.210)	(0.280)	0.460	0.640	0.530	0.470
20°	(0.200)	(0.230)	0.250	0.325	0.520	0.780	0.640	0.580
45°	(0.245)	0.290	0.310	0.450	0.780	1.180	0.960	0.860
60°	0.295	0.385	0.390	0.590	1.080	1.780	1.440	1.190
70°	0.425	0.530	0.500	0.800	1.570	2.440	2.000	1.600
80°	0.780	0.850	0.800	1.380	2.450	3.680	3.150	(2.850)
85°	1.180	1.290	1.180	1.940	3.330	(4.640)	(4.350)	.....
87° 30'	1.480	1.780	1.600	2.480	(4.070)	(5.800)	(5.100)	.....
89°	1.920	2.400	2.080	2.980	(4.700)	.....	.....	.....
90°	2.500	3.100	3.800	(3.400)	.....	.....	.....	.....

Zenith distance.	1892.				1893.	Intensity from curves for special dates.		Intensity of the oxygen line. a
	Sept.	Oct.	Nov.	Dec.	Jan.	Cold wave, Jan. 10, 1893.	Hot wave, July 14-18, 1893.	
0°	(0.840)	(0.320)	(0.230)	(0.170)	(0.150)	(0.070)	1.080	0.230
20°	(0.400)	(0.370)	(0.290)	(0.200)	(0.190)	(0.085)	1.220	0.260
45°	0.580	0.490	0.390	(0.280)	(0.250)	(0.125)	1.640	0.310
60°	0.900	0.690	0.520	0.370	0.330	0.180	2.180	0.360
70°	1.440	1.010	0.775	0.585	0.420	0.305	2.520	0.425
80°	2.350	1.760	1.440	1.080	0.780	0.310	3.900	0.610
85°	(3.940)	2.590	2.160	1.680	1.120	0.485	(5.000)	0.890
87° 30'	.....	(3.430)	2.850	2.100	1.560	0.680	.....	1.210
89°	.....	(4.000)	3.600	2.800	2.080	0.940	.....	1.550
90°	.....	(4.700)	(4.800)	(3.800)	2.800	1.280	.....	2.000

Dated, BALTIMORE, October 25, 1893.

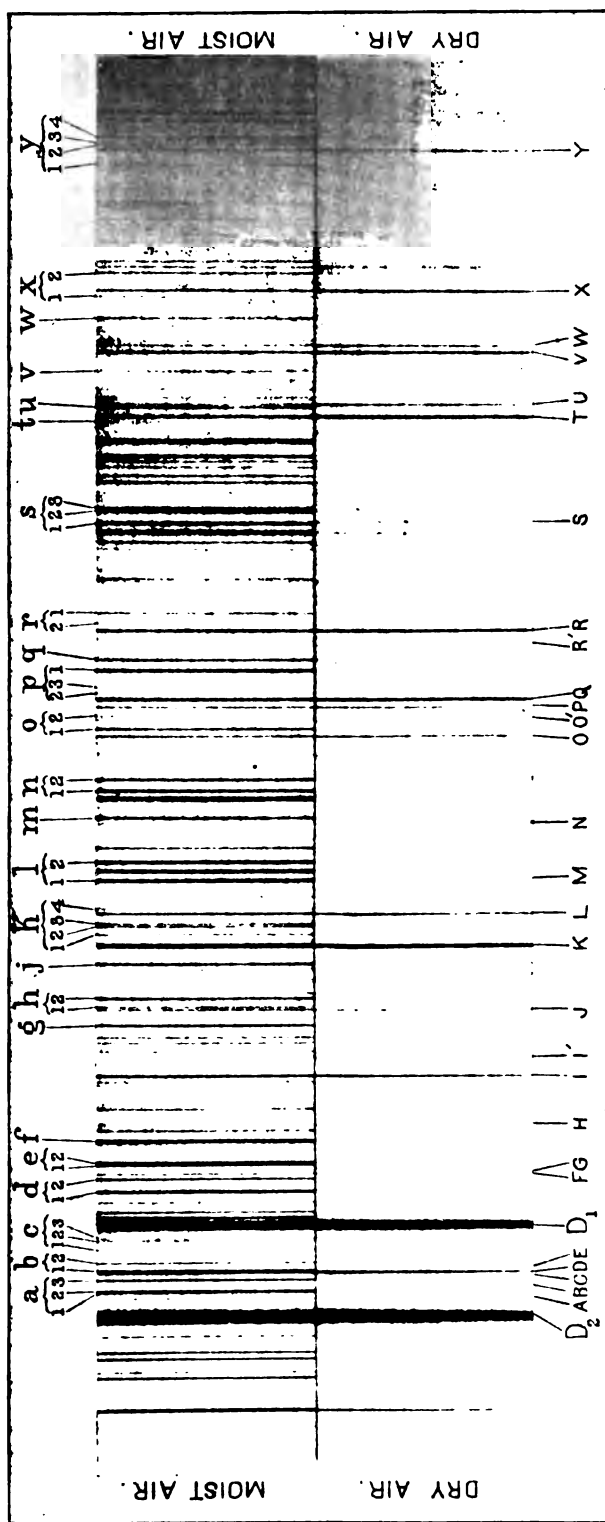


FIG. 1.—Spectrum of the rain band.

BULLETIN No. 17.—W. B. No. 88.

U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

THE WORK
OF THE
WEATHER BUREAU
IN CONNECTION WITH THE
RIVERS OF THE UNITED STATES.

PREPARED UNDER THE DIRECTION OF
WILLIS L. MOORE,
CHIEF OF WEATHER BUREAU.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.

LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., January 12, 1896.

SIR: I have the honor to transmit herewith bulletin on "The work of the Weather Bureau in connection with the rivers of the United States," and to recommend its publication as a bulletin of the Weather Bureau.

I take pleasure in acknowledging the valuable assistance rendered in the preparation of this paper by Maj. H. H. C. Dunwoody, U. S. A., assigned as assistant chief; Henry E. Williams, chief of division, and Alexander McAdie, local forecast official.

Very respectfully,

WILLIS L. MOORE,
Chief of Bureau.

Hon. J. STERLING MORTON,
Secretary of Agriculture.

INTRODUCTION.

On January 1, 1896, the Weather Bureau river and flood system consisted of 135 special river stations, equipped with standard river gauges for measuring the vertical rise of the surface of the water, and in many cases with standard thermometers for measuring air temperature. These stations were manned by local observers receiving from the Weather Bureau pay commensurate with their services. There were 44 rainfall stations, equipped with rain gauges and manned by local paid observers, and so distributed in the various catchment basins of the tributaries to important rivers as to give, in connection with the regular meteorological Weather Bureau stations, a fair approximation to the average rainfall throughout each watershed. There were 38 completely equipped meteorological stations of the Weather Bureau where river measurements were made, and 22 Weather Bureau stations which were centers from which flood warnings and forecasts of expected changes in river level were issued.

The special work of the Weather Bureau in connection with the rivers of the country is to facilitate commerce on navigable streams by publishing daily information as to water stages along the course of each river, and to issue timely warnings of floods so as to effect the saving of life and property.

As yet the rules of flood forecasting are largely empirical. The official in charge of a river center is familiar with the main river and its tributaries, the area and topography of the catchment basin, the frequency and intensity of the rainfall, especially the intensity, the average time of passage of flood crest between one station and another, and the history of past rises. The knowledge of low-water conditions, especially where bars and shoals exist, is perhaps of equally great importance as the knowledge of high water. In fact, many statements are received at the central office in Washington, from steamboat and navigation companies, to the effect that low-water conditions continue longer and affect navigation more. The people living in regions contiguous to navigable streams are materially affected in their industries by the conditions of navigation, but the destruction of life and property, as affected by the rivers, depends entirely upon flood conditions. The official in charge of a river center is expected, with the data at his command, to give information to those interested in navigation, even during low or medium stages of water, that is of great pecuniary value; but his chief and foremost duty is the dissemination of warnings when floods threaten.

Many data in regard to river stages have been published by the Weather Bureau, the Mississippi River Commission, and the United States Signal Service. From the data thus collected, and now covering many years at some stations and shorter periods at others, the following general relations have been deduced: The time it takes high water to pass from Pittsburg to Wheeling is one day; from Pittsburg to Parkersburg, two days; from Parkersburg to Cincinnati, three days; from Cincinnati to Cairo, six days; from Cairo to Vicksburg, seven days, and from Vicksburg to New Orleans, four days. From Pittsburg, therefore, to the Gulf requires twenty-three days. Similar general relations concerning the movements of other rivers have been determined. Since the time of travel is so great it naturally follows that many interfering conditions arise, tending to accelerate or retard the crest of the flood wave. No simple time rules are, therefore, possible.

The volume of water passing a station in a given time is known only at a few places, and varies, of course, with high and low water. Nor can simple rules be based upon the rainfall, as the absorptive condition of the soil is not constant, and the distribution of precipitation over the drainage area is not always determinable.

The principal rivers concerned in the Weather Bureau system are the Alleghany, Monongahela, Ohio, Kanawha, Wabash, Illinois, Tennessee, Cumberland, Mississippi, Missouri, Arkansas, and Red rivers of the central valleys; the Columbia, Sacramento, and San Joaquin of the Pacific Coast; and the Hudson, Susquehanna, Potomac, Savannah, Chattahoochee, and Alabama of the Atlantic and east Gulf coasts. Gauging stations are most numerous on the rivers of the central valleys, and rainfall stations are more numerous throughout the catchment basins of these rivers than they are on the combined rivers of the Atlantic and Pacific coasts.

The river flood service of the Bureau was reorganized on July 3, 1893, and the duty of warning communities resident along the great rivers placed in the hands of local forecast officials at the principal river centers. Each forecaster in charge of a river center has a definite section of the river system of his district to watch and forecast for. He receives the necessary telegraphic reports of rainfall which has occurred over the tributaries in his river district, the daily telegraphic data as to gauge readings nearer the source of the main river than his own station, also gauge readings on many of the tributary streams. Each forecaster is familiar with the area of the catchment basin from which his rainfall reports are received, the contour and configuration of the surface, and the permeability of the soil. A slowly falling rain of considerable volume on a nearly level and permeable soil may cause little rise, while a rapidly falling rain of the same amount on an impermeable and greatly inclined surface will gather quickly in the channels of the tributaries, and soon become a rushing torrent in the main stream. The local forecasters are furnished with all the data available relative to the history

of previous floods and, therefore, are equipped as completely as possible for the work before them. With such advantages, and with their own experience and ability, it is thought that no disastrous rise of the waters can occur in the future without adequate warning of the same having been given to all concerned.

A river bulletin board has been placed on some of the principal steamboats leaving Cairo, so arranged that the river stages can be read by people on shore and on passing steamers. Thus pilots ascending or descending the river get the latest readings at the places they are bound for.

The river gauge is a graduated scale on which the height of the river is measured. The zero of the gauge is usually at or somewhere near the level of the lowest water known. A gauge is generally vertical, and is usually fastened to a bridge, pier, or piling, and is of sufficient length to cover the greatest height of water likely to occur. When a river gauge can not be set vertically it is laid on the bank, according to the slope of the ground. The foot marks on a gauge of this kind must be accurately located by means of a spirit level, so as to agree with those on a vertical gauge. When a stage of water below the zero occurs it is read as a minus stage. It is not desirable to change the zero point after readings made from that basis have continued for any length of time.

It may be of interest to know that on account of the narrowness of the valley and the precipitous shore line of the Ohio the water in the river must show rises varying from 30 to 50 feet before the danger line is reached. At Cincinnati the danger line is 45 feet above the zero of the scale, and a height of 71 feet above zero has been recorded. On the Upper Mississippi the danger lines average about 15 feet above zero, but from St. Louis southward to Vicksburg they average about 35 feet, while at New Orleans, with its great system of levees, the danger limit is but 13 feet above zero.

In the early history of the river system the data received from the various river stations, though meager, were sufficient to permit useful warning of marked changes in the river levels. In the spring of 1874 this branch of the Bureau had its first experience with destructive floods. In that year floods devastated the valleys of the Lower Mississippi, the Arkansas, White, Red, and other rivers, causing crevasses in the levees and inundating large areas of bottom lands in the Mississippi Delta. The value of the special reports which were telegraphed at that time by the Weather Bureau could scarcely be determined. They were the only reports sent directly to the people of the flooded districts, and showed daily the coming rises and falls of the water. A study of these floods showed the necessity of establishing for each of the rivers a certain depth of water above which the stages were dangerous to river interests. These points were designated as "danger levels" and "danger lines," and were established for the Mississippi,

Missouri, and Ohio rivers during that year. In prosecuting this work, data from the best obtainable authorities were collected and compiled for the construction of a chart of the basins and watersheds of the principal rivers. A river slate was designed, on which were outlined the average grades of the beds of the different rivers at the different parts of their courses. The object in preparing this chart was to facilitate the tracing of flood waves, and their movement from one place to another. When an unusually heavy rain was noted in any watershed, it was known into what rivers it must flow and about the amount of rise that would result. A knowledge of the rapidity with which the flood would travel and of the rivers it would pass made it possible not only to follow its course, but also to give timely warning of its approach.

Some idea of the vast destruction of property due to floods may be gathered from the statement that the floods of the spring of 1881 and of 1882 caused a loss of not less than \$15,000,000 to the property interests of the Ohio and Mississippi valleys. It may also be noted that the flood of the spring of 1882 caused a loss of 138 lives in the region from Cairo southward to New Orleans.

In forecasting stages of water during such flood periods as the two mentioned, it must be borne in mind that precipitation may be only an inconsiderable factor. In those cases vast quantities of snow, which had accumulated during the winter, overlay the Northern States, and with the early rains of spring came abnormal heat, causing a very rapid melting of the snow lying over many of the watersheds. In these floods it is probable that the sudden coming of abnormally high temperatures was a more potent influence than the immediate precipitation.

The floods of 1884 began in the Ohio Valley in February, when the river reached the highest stage on record. The Mississippi River, from Cairo to the Gulf, also reached a very high stage. Ample and timely warnings were telegraphed to all available points throughout the Ohio Valley, and the resources of the Bureau were taxed to the utmost in the interests of the flooded districts. The damage caused in the Ohio Valley by this flood could hardly be calculated. In the region about Cincinnati alone the loss of property was variously estimated at from \$10,000,000 to \$26,000,000.

From June, 1889, to July, 1893, the care and supervision of the flood service of the Bureau were intrusted to a single individual, and a considerable extension of the system was made in the way of establishing rainfall stations near the head waters of the more important tributaries of the great rivers. In the early part of June, 1889, forecasts were made twelve to twenty-four hours in advance of the flood which reached the city of Washington, and the value of property saved in this city alone was many times greater than the annual appropriation for the entire flood service of the country.

In the spring of 1890 the Lower Mississippi Valley was flooded for a

distance of 40 miles back from the river, in the States of Missouri, Arkansas, Mississippi, and Louisiana. The special flood warnings, which were amply confirmed by subsequent stages of the water, were issued from Washington in advance of the flood, and in several instances far in advance of the flood crest.

Instances are numerous, but it is not necessary here to state them, showing the vast utility, from a commercial standpoint, of a thoroughly equipped Government flood-warning system, notwithstanding the fact that the forecasts are based upon empirical reasoning and are therefore subject to more or less error. The allotment from the annual appropriation for the support of the river and flood system of the Weather Bureau is not greater than the value of property that may be saved in one of the rooms in the cellar of an ordinary commercial house.

In considering the relation of the Weather Bureau to the hydrography of the country it should not be forgotten that to-day there are about 2,000 standard rain gauges quite uniformly distributed throughout the region east of the Rocky Mountains, from which daily measurements of precipitation are received by mail at the central office each month. In the Rocky Mountain and Pacific Coast region about 1,000 gauges are placed, but on account of the paucity of population there are many important regions from which proper data are not being received. Especially for the purposes of irrigation, measurements of snowfall on the high mountain ranges are valuable, but the present distribution of observation stations is inadequate to properly record the conditions.

WILLIS L. MOORE,
Chief of Weather Bureau.

WASHINGTON, D. C., *January 12, 1896.*

CONTENTS.

	Page.
River reports and flood warnings.....	13
The Weather Bureau and river floods	13
Value of the river and flood service.....	21
River districts and stations.....	41
List of special river stations.....	42
The system of flood warnings.....	44
Records of river stages.....	44
Tables of distances, river tributaries, and rate of flood movement.....	46
Notes on rivers and floods.....	50
Albany, N. Y. By A. F. Sims, observer	50
Augusta, Ga. By D. Fisher, observer	51
Atlanta, Ga. By George E. Hunt, local forecast official.....	52
Cairo, Ill. By W. T. Blythe, local forecast official.....	54
Cincinnati, Ohio. By S. S. Bassler, local forecast official.....	58
Charleston, S. C. By L. N. Jesunofsky, local forecast official	58
Chattanooga, Tenn. By L. M. Pindell, observer	68
Davenport, Iowa. By F. J. Walz, observer	70
Dubuque, Iowa. By T. W. Ruete, observer.....	73
Fort Smith, Ark. By J. J. O'Donnell, observer	74
Hannibal, Mo. By William A. Munger.....	75
Harrisburg, Pa. By Frank Ridgway, observer.....	76
Kansas City, Mo. By P. Connor, local forecast official.....	81
Keokuk, Iowa. By Fred. Z. Gosewich, observer.....	81
Knoxville, Tenn. Report of Chief of Engineers, U. S. A., 1893.....	82
Little Rock, Ark. By T. H. Clarke, local forecast official	83
Memphis, Tenn. By William M. Wilson, observer	85
Montgomery, Ala. By F. P. Chaffee, local forecast official.....	87
Nashville, Tenn. By J. B. Marbury, local forecast official.....	89
New Orleans, La. By R. E. Kerkam, local forecast official.....	89
Parkersburg, W. Va. By H. W. Richardson, observer.....	90
Portland, Oreg. By B. S. Pague, local forecast official	92
Raleigh, N. C. By C. F. von Hermann, observer	97
Redbluff, Cal. By Maurice Connell, observer	99
Sacramento, Cal. By James A. Barwick, observer	100
St. Louis, Mo. By H. C. Frankenfield, local forecast official	101
St. Paul, Minn. By P. F. Lyons, local forecast official	103
Sioux City, Iowa. By U. G. Pursell, observer	104
Vicksburg, Miss. By R. J. Hyatt, local forecast official	105
Yankton, S. Dak. By H. G. R. Swinhoe, station agent.....	106

ILLUSTRATIONS.

	Page.
Outline of the west branch of the Susquehanna River	78
Gauge relations between Cairo and Memphis, and Memphis and Helena hydro- graph.....	86
System of river forecasting—Keokuk and Hannibal, one day's interval.....	102

RIVER FLOOD SERVICE OF THE UNITED STATES.

RIVER REPORTS AND FLOOD WARNINGS.

THE WEATHER BUREAU AND RIVER FLOODS.

Prior to 1873 observations of river stages were made at a limited number of points by the United States Engineer Corps, and at some of the more important river ports regular readings of the height of the water were taken under the direction of the municipal authorities. In that year the work of making daily observations of the height of the water in the rivers was formally begun by the Weather Bureau, and the water stage at each station of observation on the principal rivers was telegraphed with the weather report daily to other river stations, where the various readings were bulletined and published in the daily press for the information of all concerned. At the central office at Washington the telegraphic reports were used for determining changes in the stage of the several rivers for the benefit of river commerce and for forecasting the occurrence of destructive floods. The stage of the water reported usually indicated the height of the water above low water mark, and in places where the water has since fallen below the zero of the gauge so determined no changes have, as a rule, been made in the elevation of the gauge. When, therefore, the water has fallen below the zero of the gauge so established, the readings have been reported as — (minus) and have indicated the distance of the water surface below the zero mark on the gauge.

The gauges used have not conformed to any standard pattern. Some have been constructed by the Government and some by the cities in which they are located. At many points they have been marked on the piers of bridges, or are composed of stones or timbers laid along the incline of the river bank. A necessary feature of the gauges has been that their construction would permit of accurate readings of the vertical height of the water surface above the zero of the gauge.

River notes were first regularly incorporated in the Monthly Weather Review in May, 1873, and consisted of a summary of the more important changes in the water stages of the larger rivers. Since that time the Review has presented a monthly history of the water fluctuations and floods of the principal waterways of the country. The chapter devoted to rivers has also contained notes bearing upon inland navigation both

upon the rivers and the Great Lakes, and forms a record of the dates of closing of navigation by ice and low stages of water, and of the dates upon which navigation has been resumed.

In addition to reports of the water stages, daily observations of surface and bottom water temperatures of the rivers and lakes and on the seacoast were made for the use of the United States Commissioner of Fish and Fisheries, the object being to determine the proper rivers and lakes in which to place the different varieties of food-fish. Announcements of probable approaching changes in temperature calculated to cause the freezing or opening of canals were also sent to those interested in canal navigation.

In the following year a circular dated March 25 was issued which showed the range between high and low water marks on the Western rivers, and the height at which rises became dangerous along their banks. This was said to have been the first systematic attempt to establish a danger line on those rivers. This circular elicited correspondence which contained much additional valuable information concerning the rivers, which was utilized in the current work of the office and incorporated in subsequent published river statistics.

In 1877 steps were taken to extend the plan of river reports to the rivers of California and Oregon with a view to forecasting rapid rises and falls, which involved grazing, agricultural, and commercial interests, and in the following year river reporting stations were established at a number of points in those States. In 1880 arrangements were made for the construction of gauges and the transmission of telegraphic river reports at points on the Rio Grande River. In that year 23 special river stations, exclusive of the regular stations of the Bureau, were in operation on the rivers east of the Rocky Mountains, and 6 special river stations had been established in California and Oregon.

The second important flood in the history of the Weather Bureau occurred in the spring of 1880, when many of the streams of the Southern States rose above the danger line. At Cairo the Mississippi passed the danger line March 9, and reached 44 feet 7 inches, 4 feet 7 inches above the danger line from the 21st to the 25th, and fell below the danger line on the 30th. At Memphis the danger line was reached on the 18th, and the water continued slightly above that point during the balance of the month. At Vicksburg the danger line (41 feet) was reached on the 11th, and the stage of water increased to 42 feet 11 inches at the close of the month. The water at New Orleans reached the danger line on the 10th, and the maximum stage, 13 inches above the danger line, was reported on the 28th. Although several crevasses occurred in the Lower Mississippi levees, little damage was caused during the month of March in that region. At Cairo, however, about one-fourth of the city was flooded to a depth of 3 to 5 feet. High water also caused some damage along the Tennessee, Cumberland, Alabama, and Chattahoochee rivers. These freshets resulted from very

heavy rains in the Southern States, and in the basins of the Cumberland and Tennessee rivers. The Mississippi River continued above the danger line from Vicksburg to the Gulf during the following month of April. A number of breaks occurred in the levees of the Lower Mississippi and tributaries, causing considerable damage to farming lands, drowning stock, and interrupting traffic. Floods also occurred in the rivers of California in April. The Lower Mississippi gradually subsided below the danger line during the last half of May, after having been at flood height during a period of about ten weeks. The information previously collected and collated relative to the rivers of the flooded districts made it possible to foresee the sweep of the flood tides from their origin in the rain-deluged mountain districts of the Southern States and Tennessee along their southern course to the Gulf, and in the case of the Cumberland and Tennessee to their junction with the Lower Ohio, and to calculate their velocity along the Lower Ohio and Lower Mississippi. These tides were supplemented by heavy rains along the courses of the rivers, and previous study of the influence of copious rains in the watersheds of the different streams allowed a just estimate to be made of the effect of these rains upon the water stages, and permitted timely information and warnings by telegraph to the threatened sections.

In June, 1881, the work of revising the circular of information regarding rivers was begun, the new edition to include new data contained in replies to a letter of inquiry that had been sent to all observers. In February, 1881, destructive floods occurred along many of the rivers of the country. The following comments on these floods in the Monthly Weather Review are interesting: "It becomes necessary to note one of the most important features of the month, and in connection therewith to consider two predominating influences in the production of remarkably serious consequences that have resulted in a vast destruction of property, the counterpart of which has not transpired in some sections for twenty years. These two causative elements have been confined to different periods of the month and widely separated portions of the country. The first, a result of excessive precipitation, was experienced throughout the Pacific Coast and northern plateau regions and along the west Gulf Coast between the 1st and 6th; the second, due to continued high temperature, the maximum of the month, operated throughout the Ohio Valley and the Middle States, in northern Ohio and Indiana, from the 10th to the 16th, suddenly releasing the ice-bound rivers and converting the huge snowdrifts into torrents of water." Destructive floods continued throughout the great central valleys and the Southern States during March, 1881. The Mississippi River rose 10 to 11 inches above the danger line from Cairo to the Gulf, the Ohio continued high, and the Savannah River at Augusta rose to 32 feet 4 inches, the highest point since 1865. The Mississippi and Missouri rivers maintained dangerous heights during

April. The Monthly Weather Review contained the following general reference to these floods:

"This subject assumes more than usual interest during the present month (April), because of the unprecedented loss of life and property, and, not least, the extreme height to which the water rose during the prevalence of the flood. In connection herewith, as presenting some of the probable causes which were at work in the production of this great calamity other than the immediate influence of the breaking up of ice, it will be well to note that in the Northwest, up to about the 12th, snow was on the ground to a depth of 15 to 50 inches, the accumulation of almost the entire winter, and in the Upper Mississippi Valley as far south as Burlington, Iowa, it varied from 3 to 5 feet. In this connection it will be of interest to recall the fact that during the month of March, just past, these regions were subjected to the heaviest snowstorms experienced, in many instances, for a period of twenty-five years. With this remarkable accumulation of snow there appeared the preserving concomitant of very low temperatures, for, as records will show, the mean temperature for March throughout the Upper Mississippi and Missouri valleys was 1.4° to 3.1° below the normal, a very important factor, and tending materially to prevent the gradual and therefore harmless disappearance of the large mass of snow. Further, it will be remembered that during the past winter ice formed in the Western rivers to a thickness and extent, in several instances, never before realized. With these conditions precedent the month of April opened with occasional heavy falls of snow and low temperatures, the minimum of the month, which ranged from -14 to $+18$, occurring between the 1st and 12th. Following this the temperature rose slowly until the 20th, after which the change was more rapid, reaching the maximum of the month between the 22d and the 26th. It would seem that in the above we have an epitome of the principal forces incident to the remarkable floods of April, 1881. Roughly estimated, but, nevertheless, said to be underrated rather than exaggerated, the loss in property has been placed in money value at the following figures: Over the territory from British America southward to the latitude of Sioux City, Iowa, \$3,500,000; from Sioux City to the latitude of St. Louis, \$2,500,000." In June, 1881, heavy rain caused destructive floods about the head waters of the Ohio River.

The destructive floods in the Lower Mississippi Valley of the spring of 1882 were made the subject of Signal Service Notes No. XV. The data upon which this paper was based were obtained through forms containing a set of seventeen questions relative to the floods which, with letters of transmittal, were widely distributed throughout the flooded districts. Three hundred and seventy-two persons filled in and returned these forms. In addition to the data so obtained the records of 22 regular Weather Bureau and 57 volunteer river observers and 15 river stations in the Mississippi, Missouri, and Ohio valleys were used,

The tables prepared showed that the floods of 1882 continued longer and were of greater depth than those of any year since 1873. In looking into the causes of floods, tables were prepared which indicated the relation between the floods of the various rivers and precipitation in the several watersheds, and the effect of melting snow upon the stages of the several rivers. The various conditions which appeared to favor and cause floods were also summarized. The estimated loss of life in the Mississippi Valley south of Cairo during this flood was 138 persons, and the loss to property was placed at \$9,655,000.

The floods of 1883 began in February, and caused the greatest damage in that month in the Ohio Valley. In the Lower Mississippi Valley the river did not attain its greatest height in February, although the water was above the danger line as far south as Vicksburg. The flood continued in the Lower Mississippi Valley during March, and although less destructive than in 1882, caused loss of life and great damage to property, especially in Arkansas.

The system of river reports was greatly extended during 1884, a special appropriation having been made for that purpose. The floods of 1884 began in the Ohio Valley in February, when the river reached the highest stages on record, and inundated cities, towns, and large areas of country, causing immense loss of property. The Mississippi River from Cairo to the Gulf reached a higher stage than in February, 1883. Ample and timely warnings were telegraphed to all available points throughout the Ohio Valley, and the resources of the Bureau were taxed to the utmost in the interests of the flooded districts. The damage caused in the Ohio Valley by this flood could hardly be approximated. In the region about Cincinnati alone the loss to property was variously estimated at \$10,000,000 to \$25,000,000. The flood continued in the Lower Mississippi Valley during March, and the water at New Orleans exceeded by 1 inch the high stages of 1873 and 1883. Destructive floods also occurred in California in that month. In November, 1884, special instructions were issued for the guidance of river observers in erecting gauges, taking observations, rendering reports, etc., and on January 1, 1885, the special river stations were arranged in sections and placed in charge of Weather Bureau observers at section centers. These centers were usually located at some important city, where the river reports in the vicinity could be readily collected for the benefit of the river interests. On that date the measurement of the depth of water was changed from feet and inches to feet and tenths of a foot. During the year ending June 30, 1885, 25 new river stations were established, giving a total of 62 special stations in addition to the regular reporting stations of the Bureau. The special study which had been pursued by the aid of the excellent and growing river service led to a determination of the rate of travel of freshet waves in rivers furnished with reporting stations, and enabled the central office to issue special bulletins containing timely warnings of the approach of dangerously

high stages of the water in the several rivers. A number of cases are cited in the annual reports in which the estimated value of property actually saved by these warnings aggregated hundreds of thousands of dollars.

In the following year there were 68 paid special river stations in operation, and during 1887 this number was maintained. The disastrous floods which had occurred during the preceding few years prompted additional and careful study of the river-flood problem. This study was made with a view to a more accurate determination of the extent and continuance of great floods many days in advance, and was directed more especially to the condition of the earth when heavy rains occurred, the amount of rain, and the average loss of water by evaporation and absorption. With a view of improving the river service, all the important river gauges were visited in that year, their zeros carefully determined, and every precaution taken to insure the greatest possible accuracy in the river observations. A system of rainfall stations was also arranged from July 1, 1887. These stations were carefully located at suitable points in the great watersheds of the country near the sources of the principal tributaries of the larger rivers. The observers at these stations were paid a nominal sum daily for their reports, which were mailed weekly to designated centers, and in case of heavy and excessive rainfall this information was transmitted by telegraph to a designated Weather Bureau station, in order that the information might be promptly used for the preparation and distribution of such warnings or forecasts as the judgment of the observer or forecast official might dictate. Owing to a lack of funds, the river reports were discontinued during a portion of 1887. When, however, the stage of water in the Lower Ohio and Mississippi rivers became dangerous, the numerous and urgent requests for a continuance of the reports made manifest their great importance, and they were resumed at the expense of other important work until the floods subsided.

No marked changes were made in the system of river observations during 1888. The principal floods of the year were noted as follows: In May a destructive flood prevailed in the Upper Mississippi River, causing great loss of property in the cities and towns along its banks in the States of Minnesota, Wisconsin, Iowa, Missouri, and Illinois. In July heavy rain caused destructive freshets in the Upper Ohio River and tributaries, and in streams of the Alleghany Mountain districts. During August destructive freshets, due to heavy rains, occurred in many portions of the Southern States. Floods inundated lowlands and caused great damage to the cotton crop in the south Atlantic and east Gulf States in August, 1888.

On June 1, 1889, the care and supervision of the river and flood service of the Bureau was intrusted to a single official. Prior to that time the responsibility for the maintenance of the river stations and the prediction of the stages of the water was divided between three different

divisions. At that time observations of the height of rivers were made at 70 places on 26 rivers. At many of the more important points these observations were continued throughout the year; at other points they were made weekly, excepting during the months in which floods were likely to occur, when the stages were telegraphed daily to Washington and to section centers. The river stations were supplemented by 45 rainfall stations, located near the head waters of the more important tributaries of the great rivers; from these stations rainfalls of 1 inch or more in twenty-four hours were telegraphed to section centers. On July 1, 1889, the time of making the river-stage observations was changed from 2 p. m. to 8 a. m. This change was made in order that the observations could appear in the afternoon press; by the former method, the reports were issued too late for the evening papers. In addition to the regular 8 a. m. observations, readings were made at 5 p. m. daily, for the benefit of the morning papers.

In the latter part of May and the early days of June of this year very destructive floods occurred in Pennsylvania, Maryland, western New York, and West Virginia. In connection with these floods, forecasts, based upon general meteorological conditions, were made twelve to twenty-four hours in advance, and while the value of property saved by these warnings in Washington City alone was far greater than the annual appropriation for the entire flood service of the country, yet had money been available for the placing and maintenance of proper gauges and rainfall stations the forecasts could have been made with greater exactness and been the means of saving a much greater amount of property. In 1889 the State of South Carolina established a number of river stations to be under the control of its State weather service. Additional investigations were carried on during that year by the Weather Bureau, which considered the rainfall over the entire watershed of the Mississippi River and its tributaries, the possible evaporation, the amount of water the saturated air could contain, the quantity of water which is held in the soil and given out as a perennial flow, and that which drains into the sea.

In the spring of 1890 the Lower Mississippi Valley was visited by one of the most disastrous floods ever experienced in that region, and along the lower course of the river the water rose 1 to 2 feet higher than the highest stages previously recorded. Although extended lengths of the levees had been recently repaired, strengthened, and raised under the direction of the Mississippi River Commission, much of the newly constructed work was unable to withstand the long-continued pressure and wash of the water, and, after flood conditions had continued nearly a month, the levees began to give way at many points, flooding the country for a distance of 40 miles back from the river in the States of Missouri, Arkansas, Mississippi, and Louisiana. Special river bulletins and flood warnings, which were amply confirmed by subsequent stages of the water, were issued from Washington in advance

of the destructive floods, and in several instances far in advance of the flood crests.

During the following year observations of river stages were made at 27 regular Weather Bureau stations and 109 special river stations, and these were supplemented by 50 rainfall stations. Thirty-eight river stations were established during the year, a majority being located in the Southeastern States for the benefit of the interests along the Alabama, Coosa, Tallapoosa, and other rivers in that section. During the Ohio and Mississippi valleys floods of the early part of the year, bulletins showing the daily stages and changes and containing definite predictions for several days in advance were widely distributed throughout the sections interested. A report was also issued, entitled "Practical rules for the prediction of flood stages of rivers in the United States." The publication of the stages of the principal rivers of the United States, previously begun, was continued, and three parts of this compilation were completed, i. e.:

"I. Stages of the Ohio River and its principal tributaries, 1858 to 1889, inclusive." "II. Stages of the Mississippi River and its principal tributaries, except the Ohio River, 1860 to 1889." "III. Stages of miscellaneous river stations in California, Oregon, North Carolina," etc. These volumes show all the river stages observed by the Weather Bureau up to January 1, 1890, except for places where the stages had already been printed by the Mississippi River Commission.

In 1892 8 a. m. river observations were made daily at 191 stations; at a number of these stations, however, the readings were taken only during the months in which high water was likely to occur. Records of these stages were preserved and printed by the Weather Bureau, and records of stages taken at other points on the principal rivers were printed by the Mississippi and Missouri River Commissions. The Annual Report of the Chief of the Weather Bureau for 1891-92 contains tables giving the following classes of data relating to the navigable rivers of the country:

Table I gives the river discharge, or quantity of water passing a place in cubic feet per second, at high and low water at a few places for which the amount has been determined.

Table II gives some of the principal information in regard to the Weather Bureau stations, as follows: (1) River station and river on which situated; (2) year of beginning of observation; (3) number of years of observation; (4) drainage area above place in square miles; (5) height of zero of gauge in feet above sea level; (6) height of flood line above zero of gauge in feet; (7) average number of days annually above flood line; (8) greatest number of days above flood line in a year and the year; (9) highest water and date; (10) average of annual highest waters; (11) average number of days annually above average highest water; (12) average date of highest water; (13) lowest water; (14) average of annual lowest waters; (15) average num-

ber of days annually below average lowest water; (16) greatest number of days below average lowest water, and the year; (17) average date of lowest water.

Table III contains mean stages of rivers for months, years, and for five and ten year periods at places where there was a sufficiently long record. Plates were also published giving the curves of river stages, or composite hydrographs, at a number of places for which there were long records.

No further marked changes were made in the system of river observations and forecasts until July 1, 1893, when the immediate supervision of the river service and the predicting of river changes for their several districts was delegated to the various local forecast officials of the Bureau. This duty has been satisfactorily performed by these officials since that date, under the general supervision of the central office at Washington.

In order to determine the value of the work of the river and flood service in the various sections of the country during the last two years, a circular letter was addressed to certain observers of the Weather Bureau, directing them to forward to this office within a week a brief statement showing the particular interests in their communities most affected by river conditions. Also an estimate of the value of the warnings of floods and high water, and all instances within the past two years where the success of the warnings has been marked.

VALUE OF THE RIVER AND FLOOD SERVICE.

The following reports were rendered in response to the foregoing directions:

ATLANTA, GA.

There are no interests whatever in this community affected by river conditions, the nearest stream, the Chattahoochee, being 8 miles distant. At Rome, in the northwest portion of the State, every business interest in the city is vitally affected by the rivers. Occupying a narrow, V-shaped peninsula between and just at the point of intersection of the Oostenaula and Etowah rivers, two streams that flow with remarkable rapidity from their mountain sources, it is so dangerously situated, that it appears incredible that a city should have been built at such a place. Rains lasting two or three days, and aggregating from 5 to 7 inches, at Rome and at points above on the Oostenaula and Etowah, will send the Coosa River at Rome from the zero of the gauge to above the danger line within forty hours or less time; and as there is not a house in the city used for business purposes that has not been flooded from 1 to 15 feet, it is no exaggeration to say that the value of reliable flood warnings is incalculable, all merchants being constantly prepared at short notice to move their wares and other property to the upper stories of their buildings. The cost of such moves is, however, considerable, not to mention the damage by handling, breakage, etc.; consequently the next most injurious thing to the flood itself is the false warning of one. Recently, while in Rome for the purpose of getting a better idea of the river conditions there, leading citizens informed me that should a flood come suddenly and without warning upon them, the loss would exceed \$1,000,000 and probably amount to as much as \$2,000,000. Though there has been much uneasiness at times, the water has not reached the danger line at Rome during the past two

years. The last floods occurred in January and April, 1892, previous to both of which timely warnings averted great loss to merchants, manufacturers, and other business interests. Above Rome, on both the Oostenaula and Etowah, farming lands are often badly washed just before planting time, after all preparations have been completed for a new crop, but as the most disastrous floods occur during the late winter and early spring, the damage to growing crops is not often very great. I should also mention that the railroads entering Rome suffer great damage by washing of embankments, etc.

Along the streams south of this station, the Chattahoochee, Flint, Ocmulgee, Oconee, and Altamaha, the interests affected by river conditions are largely of an agricultural character, though unusually high waters occasionally prevent steamboats from passing under bridges on the Chattahoochee, and also interrupt milling operations on the same stream. Should freshets occur about harvest time warnings would enable farmers to save at least a portion of their crops, but occurring at other times the only benefit they derive is in saving their live stock by driving them to safe places. There are lumbermen and sawmill owners on all these rivers who are greatly benefited at all seasons by the warnings, but to what extent it is impossible to estimate. The only warnings ever sent from this office, so far as the records show, were those I issued on the 14th and 15th of last March, and another issued from your office on March 20. River observers on the Chattahoochee, Flint, Ocmulgee, and Oconee rivers all write that those warnings enabled farmers to save live stock that otherwise would have perished. At Macon, on the Ocmulgee River, the warnings were published in the papers, and caused a number of families to move from the bottom lands near that city, which were soon after their departure under several feet of water. (I sent a telegram to Macon the morning of March 16, notifying them that the river would reach the danger line by the morning of the 17th.)

AUGUSTA, GA.

For a distance of about 20 miles below the city a number of farms are in operation in the river bottom which produce chiefly corn and hay, and the yield of both in favorable seasons, from April to November, is very large, provided the river stage does not pass beyond 22 or 23 feet. The river warnings are communicated at once to the owners of these farms, and also to the superintendent of the Port Royal and Augusta Railroad, whose tracks follow close to the river on the Carolina side for a distance of about 60 miles. This road, through its telegraph and train service, willingly and promptly sends the warnings out, and has implicit confidence in the river service of the station. Very little trouble was experienced from high water in 1893. On October 9, 1894, a river warning was issued at 11 a. m., when the gauge measurement was 6.2 feet, stating that the water would reach 30 feet; on the night of the following day it had reached its highest point, 28 feet. The estimated value of corn and hay saved by this warning was \$1,100. On December 12, 1894, at 10 a. m., a prediction was made that the river, which then stood at 10.1 feet, would go to 26 feet on the following day. The height of this rise was 26.3 feet, but as all crops had been gathered, no special harm was done, and the benefit was confined to those who drove their stock to the high grounds. On January 9, 1895, at 10 a. m., a special notice was sent advising the community of a 30-foot river stage within the ensuing thirty-six hours, the stage at that time being 11.9 feet. The city engineer had all sewer gates opening into the river closed, in order to prevent them from bursting when the high water should arrive, and large droves of hogs which were being wintered in the bottom lands were removed to safer grounds without loss. The height of this rise was 30.4 feet.

CAIRO, ILL.

To enumerate the interests affected by river conditions in this vicinity would be to name every branch of business and industry carried on here and along the rivers.

Those most directly injured by floods and extreme low water are, first, the farmers, and, second, the steamboat and river transportation interests. As the river approaches the high-water mark, against all stages below which most of the towns and cities are now protected by levees, the anxiety and fear of financial loss increase, and the interest manifested in obtaining river news becomes intense in all classes, both in the country and city districts. It may be said that whatever conditions affect the steamboat or river transportation interests at any season of the year affect also, to a greater or less degree, the interests of producers, shippers, manufacturers, and dealers. Steamboat traffic is carried on below Cairo throughout the year, but the logging interests on its tributaries, the Obion, Forked Deer, and Hatchie Rivers, and the several bayous and creeks, are dependent upon stages of 25 feet and above on the Cairo gauge for the floating of their stock. Consequently all labor interests are favorably affected by rises when the stage is between 25 feet and the danger line.

The issue of the daily river forecasts at this station for the Ohio River from Evansville to Cairo, and for the Mississippi River from below St. Louis to Memphis, began November 16, 1893. Since that date the highest water has been 37 feet, or 3 feet below the danger line.

CHARLESTON, S. C.

Sudden and unheralded rises in the streams of this section cause great loss of live stock in the lowlands. The warnings of the Bureau have been the means of saving much stock. Steamboat men utilize the reports from the upper streams in forming opinions as to the available depth of water for navigation purposes, and the South Carolina Steamboat Company has frequently acknowledged its indebtedness to the Bureau for valuable information concerning the stage of water in the rivers of the State. The Santee, Great Pedee, and Waccamaw Steamboat and Transportation companies are also greatly interested in navigation on the Santee, Black, Great Pedee, Little Pedee, Wateree, Congaree, and Waccamaw rivers. Immense quantities of tar, rosin, turpentine, lumber, cotton, rice, and other commodities are transported over these streams annually, and it frequently happens that an entire month's output of tar, rosin, turpentine, and lumber must be removed within a short period in order to take advantage of a rise sufficient to transport these goods by water. These rises appear, usually, in the upper streams several days in advance, and the Bureau reports give considerable time in which to prepare for the rise. It is estimated that \$35,000 has been saved to the steamboat men alone by these reports, and in August, 1893, one timely warning saved property valued at more than \$6,000 on the Santee River. The Sea Island cotton interests suffer considerably from high water and storm tides. This particular growth of cotton is raised to some extent along streams close to the ocean. When flooded, it loses its flexibility, the staple becomes yellow, and the plant soon dies. The cutting and rafting of lumber and logs is one of the important industries, and high stages of water are necessary to float this material to the saw-mills; and during the periods of high water in August, September, and October, 1894, mill men were enabled to float large quantities of logs and cut timber by the aid of the warnings and forecasts of the Bureau. One lumber firm estimates that the river reports provide the means of saving them \$10,000 a year. The officers of the United States Engineer Corps state that they are greatly aided in their dredging operations in the various streams of the State by the reports and forecasts of the Bureau.

The flood and storm-tide warnings of August 27, 1893, saved property to the amount of \$350,000 along the South Carolina coast. The warning of heavy rains, floods, and unusually high tides sent out September 25, 1894, resulted in the saving of an immense amount of property. In the storm of October 9, 1894, a majority of the rice planters saved 10 per cent of their stacked rice from the storm tides, the estimated value of the rice saved by the warnings being \$65,000. The daily telegraphed stages of the water, especially the report from Augusta, are of great value to rice growers.

CHATTANOOGA, TENN.

The interests most affected by the conditions of the Tennessee River are those connected with steamboat and lumber interests. No dangerous stages of water have occurred during the last two years. The high water of previous years caused a great demand for the river and flood reports and forecasts. Lumber and logging interests are affected by the varying stages of the water, and, together with other river industries, derive great and constant benefit from the river stage reports and the forecasts. If this service were abandoned by the Government it would have to be continued, at heavy expense, by the community. The value of the interests on the Tennessee River at Chattanooga, and on the various tributaries which are directly affected by the river conditions, exceeds \$900,000.

CINCINNATI, OHIO.

The particular interests in this community most affected by river conditions are those of the steamboat and barge men, the coal dealers, the railroads, the merchants on the lower levels, and the gardeners in valleys in and adjacent to the city.

No estimate of the value of the warnings of floods and high water, in dollars and cents, can be given, as no data can be obtained. Excepting the frozen river during the past winter, the breaking up of which was a great standing menace, no special danger in connection with the river was encountered in the past few years. In this case the river opened so gradually and quietly, by reason of the favorable weather, that comparatively little loss was experienced. I can find no statistics of any savings or loss by high waters within the past few years. The river service is deemed invaluable, and all interested are on the alert, so that all danger of damage from rising waters is averted by reason of the timely warnings and the facilities for guarding against impending danger. It is freely admitted that no money would be a recompense for the deprivation of the Government reports of rivers and rainfall.

COLUMBIA, S. C.

The Congaree River is formed by the confluence of the Broad and Saluda rivers at Columbia. These streams have a drainage area of about 8,000 square miles in South Carolina. The topography of the section drained is broken and hilly, the slopes of the hills are steep and denuded of their original covering of forest growth, and rainfall is quickly collected and drained into the rivers, causing rapid rises even with a moderate rain. The valleys of the rivers above Columbia have very little agricultural or other value. Below Columbia the valley of the Congaree widens rapidly, and includes many thousands of acres of exceedingly fertile land on which valuable crops are subject to the overflow of the Congaree. The principal crops are hay, corn, oats, and cotton, and the land not under cultivation affords pasturage for stock. Since 1890 the Congaree has risen to or above the danger line four times, and in each case the crops were greatly damaged or completely destroyed. It has been exceedingly difficult to get definite information regarding the value of the crops lost, for the reason that owners of land in the valley refuse to discuss the subject, believing that to do so would tend to depreciate the value of the land, or rather affect its market value. There has been no attempt made to predict floods for the Congaree Valley, and the value of the warnings, if issued, would be questionable, owing to the nature of the interests affected, for it would be obviously impossible to remove growing crops, or to gather ripe crops, after the danger became imminent. Stock on lowlands could, however, be removed to places of safety. Careful inquiry has failed to discover that there has ever been any serious loss of live stock by a sudden rise or overflow of the Congaree. The lower valley is principally heavily wooded swamp land, and warnings to that part of the valley would be useful to lumbering interests. The subject of warnings of floods for the Congaree Valley has been a matter for discussion among landowners in the valley and this office for the

past year, the object being to devise some quick, sure, and cheap method of warnings that would reach the majority of interested people, but as yet no plan has been proposed that is considered at all practicable or feasible.

DAVENPORT, IOWA.

The interests most affected by the river conditions of the Upper Mississippi River and tributaries in the Davenport district are the Upper Mississippi improvement under the direction and charge of the United States engineers, steamboating, general navigation, rafting, and logging; and, in case of very high water, farmers cultivating lands on islands and low bottoms, and city wharfage and levees. During the summer and fall months the United States engineers are carrying on works and improvements in the river to the amount of a million of dollars or more, and reports of river stages and warnings of any sudden rise in the river are of immense value to them in successfully conducting operations. One or two instances occurred during the past season, when the warnings no doubt saved several thousand dollars' damage in this direction alone. There have been no very dangerous floods or high waters in the Upper Mississippi during the last two years. The river has reached the danger line at two stations only in the Davenport district since the station was established as a center. These were at La Crosse and Dubuque in May, 1894. Timely warnings were telegraphed on both occasions one to two days in advance of the predicted stage, and were accurately verified in each instance. Rafting companies claim that the river reports and warnings last spring were worth \$10,000 to \$20,000 to them, and that all predicted rises during navigation and log-rafting season, even though the rise is small when the river is low, are of vast importance and value.

FORT SMITH, ARK.

Farmers, stock raisers, lumbermen, and steamboat men are affected by the river conditions. There is no recent data on record whereby the value of property saved by flood warnings in the last two years can be estimated. From inquiries instituted by the observer there is found to be a consensus of opinion that the warnings have been of great public benefit. Extensive landowners and cultivators along the river bottoms in the Cherokee Nation have been greatly benefited by the warnings. Since May, 1893, there has been no damage by flood in this section, nor water high enough to warrant any special or general warnings. All parties interested agree as to the great advantage of being notified of dangerous and rapid rises in the river.

HANNIBAL, MO.

No flood warnings have been received since the establishment of this station. The agricultural interests are the principal ones affected by flood in this section. Across the river from Hannibal there are over 110 acres of cultivated land protected by a levee which will stand a stage of 21 feet, and warnings of a rise above that point would be of great value. On the west side of the Mississippi, commencing about 3 miles above Hannibal and extending 20 miles along the river to Lagrange, is a tract of fine farming land unprotected by levee which will stand a 13-foot stage of water without inundation. If warnings of a rise above that stage could be given a few days in advance they would be of great value to the farmers.

HARRISBURG, PA.

Ordinary rises in the Susquehanna, particularly on the west and north branches, are useful in floating logs and timber. When excessive floods are expected the lumbermen can hold their logs in the upper streams and avoid the risk of losing them in the main river. In the case of severe floods all interests in the submerged portions of the valleys would profit by the warnings. Owing to the heavy losses caused by the flood of 1889 great care must be observed in making flood warnings and fore-

casts, as great expense would attend the moving of goods and property which such a forecast would cause. Railroads, as well as the lumber, commercial, and agricultural interests, would also profit greatly by flood warnings, as it would enable them to remove cars containing valuable freight to safe places, load bridges, etc. Accurate forecasts of coming stages would dictate the action necessary to protect their property. Several of the towns along the two branches have been considering the plan of protecting themselves from inundation by the construction of dikes. Sunbury built a dike last summer, which is 2 feet above the highest flood. If this dike is ever overflowed they will be worse off than before, so a timely warning would be of great value in that locality. If the forecast was for a height but a little higher than this dike, it would be quite possible to raise it enough in twelve hours to protect the town. In 1889 the river service had not been organized on its present basis, and I feel confident if warnings had been then issued along the west branch of the Susquehanna for a flood 5 to 7 feet higher than that of 1865 hundreds of thousands of dollars would have been saved. I also believe that if careful observations are taken of the effect of rainfall on the river for the next four or five years floods can be predicted within a foot; and with that end in view the Pennsylvania Railroad will soon have completed several river gauges along the Juniata River, where they have also promised to have rain gauges placed (these to be furnished by this Bureau), and their employees will take observations and make reports to this office without expense to this Department. The Northern Central has also promised to cooperate along the two branches, and I am now waiting for them to designate the points where rain gauges can be placed. There are many conditions that enter into the problem in the lower districts—the season of the year, whether the crops are in the ground and the trees in foliage, the ground frozen or soft, covered with snow or bare, the depth of snow, and temperature.

During the flood of May 21 and 22, 1894, warnings were sent in every direction by telephone and railroad telegraph. This information was sent out the night of the 20th of May and early the morning of the 21st. The river reached its highest point, 25 feet 9 inches—within 14 inches of the flood of 1889—at 6 a. m. of the 22d flooding cellars and destroying all truck crops on the many islands in the river, and causing a few washouts on the railroads. Estimate of property and live stock saved by the warnings, \$60,000 to \$70,000.

HELENA, ARK.

I have recommended to the Department that the discharge of the tributaries or main rivers should be measured, so that an approximate could be made of the discharge at every stage, and by noticing the effect at Cairo and below we could soon tell some days in advance the probable effect of every rise. This measurement would not have to be made every year; but once or twice would give the discharge, say for each foot on the gauge. To illustrate: the Missouri River might be gauged or marked at Kansas City, the Ohio at Louisville, the Cumberland at Nashville, the Tennessee at Chattanooga, and the Mississippi at St. Louis. Minor streams like the Wabash could be gauged also. The measurements need not be at the points designated, but at such points as they could be done most accurately, owing to the conditions of the banks, etc. With all this knowledge, great experience and knowledge of other conditions would be required to make the proper forecasts. A sudden or a slow rise would have to be considered; also the condition and extent of the levees. It requires twelve to seventeen days for a rise to reach Helena from Cairo, with the St. Francis swamp not leveed. A levee is being built which, when completed, will bring the rise from Cairo to Helena in less than four days. This levee is partially constructed, and I can not tell what effect it will have on the rise here, but will have to wait and see. According to my notion, this levee will raise the water along the St. Francis point from but little at Point Pleasant, Mo. (the head of the levee), up to 8 to 12 feet at Memphis. As this levee is being built only 3 to 4

feet above the present high-water mark, it will take several high waters before it will be built to that height, and it may be abandoned as impracticable before that time. As to the effect at Helena and below, it would be but little, under certain circumstances, except to bring the river to the highest point in four days instead of seventeen. It would make a great difference at Helena should there be a sudden rise and fall at Cairo, or whether the rise was slow and the river stood at or near the highest point and then fell rapidly. With the levee completed, it would make but little difference, as the whole volume of water would be forced down the channel, instead of losing an immense amount in filling the reservoir of the St. Francis swamp.

KANSAS CITY, MO.

There are no interests of note affected by the river conditions until the river reaches the danger line. This stage has been reached but five times since 1873—the period covered by the records of this office. When the stage of water is near the danger line there is, of course, more or less apprehension lest it should continue to rise. There is no navigation on the river at this place. The interests affected by floods are in the village of Harlem, just opposite this city, some implement and wholesale houses, the packing houses in the west bottoms, and the probable washing away of railroad tracks on the river bank.

No river warnings were furnished this station previous to last summer, when the official at Omaha sent them for a month or so while the water was within a foot or two of the danger line. Previous to that time local forecasts were made and given to the public from day to day when the river approached a dangerous stage. It is impossible to place a money estimate upon the benefits that may have been derived from the warnings. The parties interested took precautionary measures against encroachment by the rising waters, but just what would have been the result had no forecasts been made public is of too doubtful a character for an estimate. No special benefits have been derived from warnings during the last two years. Some of the packing houses have asked for an opinion regarding the probable outlook for the season of high water, but it is not known to what extent they builded upon the information received.

KEOKUK, IOWA.

The river conditions are locally of most importance to lumbermen and lumber dealers, as Keokuk is the distributing point for lumber for a large territory lying in Iowa, Missouri, and Illinois. Lumber is brought by river from the northern pineries and sawmills by steamboats in large rafts, either of logs or sawed lumber, each raft containing several million feet. The time required to make a run with a raft depends upon the stage of the water, as in higher water shorter channels can be run, and much time can be saved by running the Des Moines Rapids instead of the slow process of locking through the Des Moines Canal, and the cost of delivering a raft is lessened or increased according to the stage of the water. All persons interested in steamboating are benefited by the river bulletins, and all boats landing at this point, as a rule, consult the bulletins which are displayed at the regular landings, and in some cases when boats have not landed they have sent a yawl ashore for the purpose of consulting the bulletin. Farmers on the bottom lands lying in Illinois and Missouri south of the mouth of the Des Moines River are interested in times of threatened high water, and reports reach those sections at Warsaw, Ill., Alexandria, Lagrange, and Canton, Mo., in the regular river bulletin. Flood warnings have not been sent from this station, as the rise of the river is so gradual that timely warning may be had from the regular bulletin. There has been no flood of any consequence since May, 1888. In May, 1892, and again in 1893, the river rose above the nominal danger line (14 feet), overflowing a small tract of land in Missouri, and doing no material damage. Since May, 1893, the river has not reached the danger line at this point.

KNOXVILLE, TENN.

The interests most affected by river conditions at this place are those connected with navigation, and they are affected very little from the fact that this point is nearly at the head of navigation, the river being navigable only about 55 miles farther upstream. Owing to the high river banks along this portion of the stream, farming interests along the side of the stream are never in danger from floods, while property along the banks is equally free from liability to damage. In fact, it may be generally stated that in rare cases only is there any danger to be apprehended from high water in this section. River men state that stations up the stream would assist the navigation interests.

LITTLE ROCK, ARK.

As the low stage of water in the Arkansas River at this point has continued during a longer period in the last year than ever known before, the stages of water have assumed an importance hitherto unknown. When, during the late fall and winter months, the water is too low to ship by river the large quantities of cotton and cotton seed and merchandise of all kinds, freight of this class must be hauled long distances by wagon and shipped by railroad at greatly increased expense. During low stages of the river, when a slight rise is reported in the upper river, the boats can leave Little Rock and return with a full cargo with the rise, whereas if they were not informed of the rise at the earliest possible moment it would be too late to take advantage of it after it reached this city. This condition has existed many times during the past year, and the importance of the river intelligence has been demonstrated by the increasing demand for news of this nature. River warnings of floods are of incalculable value to all the inhabitants of the Arkansas Valley from Fort Smith to the mouth of the river, but chiefly so to those of the lower valley. From information received from a flood warning they can determine just what steps to take in strengthening and repairing levees, or if the anticipated flood is so great as to make it impossible to prevent overflows, they can move their household effects and stock to safe places. Floods are not common in the Arkansas Valley, and consequently levee protection is comparatively poor and not much attention is paid to the levees until the flood seems imminent. The section of country protected by levees is small, hence a very large section is subject to overflow, and included in this area are some of the finest cotton lands. No floods have occurred in the Arkansas River during the last two years, but from the benefits derived from the flood warnings of 1892 this branch of the work of the Bureau has since assumed an importance second to none. It is impracticable to make an estimate of the money value of the warnings issued, but they were the means of saving many lives and thousands of dollars' worth of property.

LOUISVILLE, KY.

Louisville is located upon a gently undulating plain which has an average elevation of about 70 feet above low-water mark. New Albany and Jeffersonville, on the opposite side of the river, are similarly situated at approximately the same elevation. Both above and below these cities high banks rise abruptly from the shore, except in occasional places where there are spots of limited area but slightly elevated above the river. As the highest water mark shown by the Weather Bureau record was 46.6 feet, on February 16, 1884, it will be seen that only in cases of floods of exceptional volume is property generally exposed to danger in this vicinity. That portion of the city which, by its location in the depression forming the valley of Bear Grass Creek, was formerly exposed to danger from even ordinary floods, has been protected by a high earthen wall which has diverted the stream from its original course. A depth of 30 feet will flood cellars fronting immediately upon the river and a portion of Portland, a small suburb west of the city, and a rise to 35 feet will endanger a considerable amount of property. Warnings of these stages have fre-

quently proved of great value. On an average of once in three years the water rises to a stage that jeopardizes considerable property, and in such cases the warnings are of great value. The highest water during the last two years was 28.8 feet, February 22, 1893, but it resulted in no material damage. On account of the infrequency of flood stages of water and the comparatively small amount of property endangered by them, flood warnings are considered subordinate in importance to the daily reports of the fluctuations of the river, affecting as they do many and diversified interests.

The States contiguous to the Ohio and Mississippi rivers are in the main dependent for their fuel supplies upon the coal which comes from the Upper Ohio and its tributaries, and the annual consumption is many millions of bushels. Nearly all of that destined for points west and south of here has to pass Louisville, and it is of the highest importance to dealers and shippers, both here and elsewhere, to be informed as to the stage of the water in the river, particularly the depth of water in the canal, through which the coal fleets must pass. A rise or fall of even a few inches may be of great moment to this industry, and, while no data bearing upon the subject is accessible, information furnished by this office has been of unquestioned pecuniary value. This statement is true also in a lesser degree in regard to the shipping of other classes of freight and to general river traffic. The work of widening the Louisville and Portland Canal, which is in charge of the United States engineers, has been in progress for ten years or more, and can be conducted only when the water is low enough to expose a portion of the river bed. A sudden rise, even of a few feet, will endanger all the costly apparatus used in connection with the operations, and upon several occasions during recent years it has been saved through information furnished by the reports of this office. In the same manner the cement industry has been greatly benefited, since the rock used in its manufacture is obtained from the bed of the river, and the tools, tracks, engines, cars, and other apparatus are constantly exposed to danger from sudden rises.

It is only during severe winters that the Ohio is closed by ice at this point, but in the winters of 1892-93 and 1894-95 it was frozen for considerable periods. The breaking up of the ice is a serious menace to all floating property, and warnings received during the winters mentioned were of the highest value. The breaking up of the ice in January, 1893, caused the loss of \$200,000 worth of coal, but it is a notable fact that owners who took precautionary steps suffered but little loss, and it is estimated that more than the above-mentioned amount was saved through warnings of the approaching break. Warned by the experience of 1893, river men generally heeded the information furnished to them during the past winter, and, as a result, the breaking up of the ice was accompanied by practically no loss. Warnings of high winds have not infrequently been attended by the most valuable results to river interests. The most notable cases of this kind were those of March 27, 1890, which, from a conservative estimate, resulted in the saving of property valued at \$100,000 and 50 lives; and March 24, 1893, when \$20,000 and probably many lives were saved.

While the benefit of the flood warnings, in the strict sense of the word, can not be so great here as in districts subject to periodical overflow, yet the river-report service is considered one of the most important and highly appreciated features of the work of the Weather Bureau in this section.

MEMPHIS, TENN.

All business interests in this community are affected by the condition of the rivers, and when flood or high water threatens, the interest is intensified over the entire area subject to overflow. It is estimated that a little more than three-fourths of the cotton-producing territory tributary to Memphis is subject to overflow during extreme high water, or is behind the levees of the Mississippi, Arkansas, and St. Francis rivers. The great length of the season required for the maturity of cotton

renders this crop especially subject to damage from protracted high water, and when flood threatens it is of the utmost importance to know not only what portion of the lands will probably be submerged, but the probable length of time they will remain under water, in order that advantage may be taken upon the subsidence of the water to replant in cotton, if there is sufficient time, or in some other crop should the season be so far advanced as to render the maturity of cotton uncertain.

The Weather Bureau reports of the daily rainfall and river stages are the only authentic source of information accessible to the planter who has at stake probably his entire capital, and to whom a flood means ruin or privation. When a flood threatens, every scrap of information and every opinion as to the probable height the river will reach is read and discussed at every post-office and crossroad throughout the valley, and while the knowledge that a flood will occur might not enable the planter to save a pound of cotton on land subject to overflow, nevertheless it is knowledge of the greatest importance to him, as preparation can then be made to place property in a position where it will be subject to the least damage.

Flood warnings are absolutely indispensable to those directly interested in the protection of the levees. When the water reaches a danger point it is necessary to have the levees under the most careful surveillance, and to this end the interest of the people must be aroused to the possibility of danger. Nothing is so effectual for this purpose as the information furnished by this Bureau. Much credit is due Capt. A. A. Sharp, superintendent of the Yazoo and Mississippi Valley Railroad, for his efforts in furnishing information of impending floods to the people of the valley. This railroad follows the Mississippi River from Memphis to Vicksburg, and Captain Sharp has arranged with this office to obtain the stages at the principal points on the upper rivers at the earliest possible moment each morning. These stages, together with the river forecasts, are telegraphed to all stations on his line and promptly posted. This keeps the people thoroughly in touch with the latest information on the condition of the rivers, and is received at least thirty hours in advance of the daily papers. I am unable to point to any instance and say that the warning saved so many dollars—such examples are exceedingly rare; but when a planter makes a journey of 75 miles with no other purpose than to obtain the latest information as to the probable extent of the threatened flood, the value of such information to him may not be questioned. Two instances of this kind came under my personal notice during the high water of 1893.

The value of the daily river reports to those directly interested in river traffic is manifest, especially when the river is low and care must be exercised in loading in order to pass safely over shoals which may be in the channel. These points are closely watched by steamboatmen, and the daily reports of the Bureau form the basis of calculation as to the cargo a boat may safely carry. The value of such information is evident, though it is difficult to estimate in dollars and cents.

MINNEAPOLIS, MINN.

The principal interests affected by the river conditions in this locality are the lumber industry, the flour mills, and the city waterworks. When the river stage is low the season's cut of lumber can not be floated into the Mississippi, and some of the sawmills are obliged to shut down. The mills use all the water they can get for power, and when the water is low they are obliged to use their more expensive steam plants. The annual spring rise usually floods some of the cottages nearest the river bank in a district known as the "Bohemian Flats," which is located below the falls and contains a settlement of squatters. The loss is, however, insignificant. No warnings of floods or high water have been furnished to or issued from this office during the last two years.

MOBILE, ALA.

The Alabama River system is nearly a thousand miles in extent, embracing the Alabama, Warrior, and Tombigbee rivers. These rivers and their tributaries bring

the products of the mines, cotton fields, and forests to manufacturing and shipping centers. This river system has been in operation about two years, and in importance is only equaled by the daily weather forecasts. The value of the commercial products reaching Mobile through the medium of the Alabama River system varies from \$10,000,000 to \$15,000,000 annually, and when it is remembered that there are times when navigation is seriously embarrassed, if not entirely suspended, the importance of the daily river reports, the only source of information concerning the rivers, can be readily seen. River transportation has a formidable competitor in the railroad system, traversing as it does a large section of the river territory. This fact calls for the closest study of the conditions of the rivers and the rainfall by steamboatmen, as it enables them to accept or reject cargoes.

Almost daily, persons interested in river navigation call for the water stages before the information is officially issued. If reports are favorable, steamers are laden and dispatched to points which, owing to low water, have not been visited for weeks. If reports are not favorable, freight is not received. Thus it will be seen that these reports are valuable, not only to the steamboat owner, but likewise to the planter, who receives the benefit of the lower rates of water transportation. Lumbermen, loggers, and shingle manufacturers show equal interest in the daily river bulletin, all of these interests desiring high water. The recent heavy rains over Alabama, Georgia, and Mississippi show the relation this office bears to this community, and what a factor it is to the business interests. For some months the mills of the city had almost ceased operations for want of supplies, owing to a deficiency in the spring rains. Large quantities of lumber had been cut, and arrangements had been perfected to float it down to this city with the first high water. The rains mentioned were sufficient to cause the streams to reach the danger line. Immediately on receiving official notice of the coming rise, thousands of loggers were sent to the swamp country contiguous to the rivers, and hundreds of rafts were brought to the rivers and floated to this city. Without the information furnished by the reports of this office, valuable time would have been lost and very few logs would have been secured, owing to the very short period the high stage continued. A foreknowledge of high water enables stockmen to drive their cattle to safe places. The reports are of incalculable benefit during the low stages of water which continue during the greater portion of the year, as the information they contain is a leading factor in the navigation of all rivers.

MONTGOMERY, ALA.

A majority of the business interests of this community are directly or indirectly affected by high water and floods in our rivers. This city is a commissary depot for all of the river basin of this section, covering thousands of square miles, and any influence brought to bear on the agricultural or stock-raising interests is felt at once. There are thousands of acres of fine bottom land on which corn and cotton is grown which is subject to overflow. It is impracticable to gather accurate statistics of the value of such interests, but from the most reliable information obtainable the value of such interests in this county alone which are affected by river conditions will aggregate \$200,000. The manufacturing interest is not large, and would not exceed \$50,000 annually. The shops of the Louisville and Nashville Railroad and the Western Railway of Alabama are located on ground which would be flooded by extremely high water. The value of machinery and other movable property at both shops is several hundred thousand dollars. The value of the reports to the mercantile interests is also very great, as at most of the river landings where freight is discharged the means of protecting the freight from high water after it is landed are very meager, and during periods of high water arrangements have to be made in advance for the prompt removal of goods to high ground. It is difficult to estimate the value of merchandise so affected, but it is fair to assume that it would aggregate \$50,000 to \$75,000 annually. The timber interests affected by river con-

ditions are also considerable. In the swamp lands, where at times there is a large quantity of timber ready to be hauled to the mills, unexpected high water would float it away and cause serious loss. The estimated value of timber in this section so affected is \$75,000 to \$100,000 annually.

During the winter and spring most of the live stock is kept in the canebrakes of the river bottoms, on account of the better pasturage. As these are the seasons when we have our most sudden rises, our reports and warnings are of vital importance to the stock raisers, and this interest represents about \$100,000 annually.

No floods, and but few ordinary high rises, have occurred in the last two years, and in the case of the rises full and ample warnings were issued. Several days' warning was given of the high waters of March 15 to 21, 1895, the warnings being telegraphed to nearly all river stations and mailed to all postmasters at river towns within mailing distance, and while the water was not high enough to do any serious damage, it is thought that the warnings saved considerable loss of stock and other property in the bottom lands. The forecasts and warnings issued at that time have certainly increased the public confidence in this branch of our work, which in this section is one of the most important of the Bureau.

As before stated, it is impracticable to obtain more than approximate estimates as to the value of the various interests in this section affected by river conditions and benefited by our warnings, but for the Alabama and Tombigbee systems of rivers it is thought the following is a conservative estimate of the annual value of the different interests:

Agriculture.....	\$1,500,000
Stock raising	100,000
Manufactories of all kinds.....	500,000
Lumbering	200,000
River commerce (indirectly affected and benefited)	15,000,000
Total	17,300,000

The reports and warnings are also of great benefit to the officers in charge of the Government improvement of the rivers of this section, for which large and costly plants are maintained, and which our warnings have often been the means of protecting from damage by sudden high water. Railroad officials derive value from the reports during periods of high water, as they are enabled to protect their bridges and other property. The Capital City Waterworks of this city, which obtains water from an artesian supply, is also affected by river stages of 15 feet or more, and extra precautions to prevent damage are taken when warnings of stages above 15 feet are received.

NASHVILLE, TENN.

The principal interests affected by the condition of the river at this point are those connected with steamboating, lumber, munufactories, and merchants and dwellers in houses along the river banks and in the low districts. There are three large saw-mills on the banks of the river, two of which are seriously inconvenienced by a stage of 38 to 40 feet, while the third can stand 45 feet without much damage to its property. These mills are in the habit of stacking lumber on the river banks, and it frequently happens that heavy rains at points above Nashville cause quick and decided rises here. These rises are shown through reports from the special river stations at Burnside, Ky., and Carthage, Tenn., in time to notify the owners of the lumber to remove it to places of safety. If it were not for the river service, the first intimation these owners would have would be the arrival of the crest of water which would carry off a part, if not all, of their lumber. During the rise in February, 1893, one mill alone had about \$1,000 worth of lumber stacked on the banks a few feet above the water. On the 17th of that month it was seen by the reports of stations above that the danger line would probably be reached or passed during the ensuing

few days, and bulletins were issued to that effect, and warnings were given to remove all movable property above that line. A large force of men was put to work, and every foot of lumber was removed to a safe place, and none was lost. By the morning of the 21st the water had risen one-half foot above the danger line. One firm stated that this warning saved them over \$2,000. The owners of small tenement houses in the districts subject to overflow are also especially benefited by the warnings. The brick manufacturers are enabled by the warnings to bank their fires and stop their machinery, and in other ways to protect themselves and save considerable money. The danger line has been passed but one other time during the last two years—February 9 to 11, 1894. At that time the warnings were widely distributed by means of the bulletins and the telephone, and while no special instance is known, I am convinced that much money was saved by the warnings. The warnings are probably of greatest value to the steamboat interests. When the water is low and a rise occurs at the headwaters, they often send out a boat to load at some of the towns above and return with the rise. It is a very conservative estimate to say that the river service is worth to this city at least \$25,000 a year.

NEW ORLEANS, LA.

Steamboat men, coal men, and plantation owners along the rivers are the persons most interested in the river reports, as a rule. The former gauge their time of departure according to the river reports of the Weather Bureau, particularly in the Red and Ouachita trade, and it is only through such reports and accompanying forecasts, when these rivers are at a low stage, that the trips can be made. The coal interests from Pittsburg down the Ohio and Mississippi rivers are particularly large in this city, and the river reports from the Ohio are in great demand, and serve to control the time of departure of coal fleets from the upper Ohio. During the past season, when the Ohio was at a low stage for weeks—so low as to make it hazardous to attempt starting the coal fleets from Pittsburg, and at a time when coal was becoming scarce in this city—timely information of an expected rise in the Ohio through anticipated rains resulted in a number of fleets starting down the Ohio and making their way to this port without grounding or being delayed by tying up. Incidents of this character are quite numerous, and prove the great value of the river reports and forecasts during low water. The rice planters along the Lower Mississippi are also greatly interested in river information disseminated by the Bureau. Flooding rice fields by means of pumping from the river is expensive, and when the reports indicate an anticipated rise sufficient to permit flooding by means of flumes a considerable outlay of money is saved to the planters, whereas if the reverse were the case the pumping method would be resorted to as a means of making the crop.

During the periods of high and flood waters the entire public is particularly interested in the reports and warnings. Boards of levee commissioners, engineers, plantation owners along the rivers, and in fact all riparian interests, keep a watchful eye on the Weather Bureau reports. During the spring of 1893—April and May—the levee system of the State was greatly strengthened on account of the timely warnings of the Bureau. Back, or protection, levees were thrown up, temporary levees were erected at points where it was feared the river would wash over its banks, and although breaks occurred and considerable damage was done, yet without the information furnished by the Bureau it is safe to assume that the damage would have been far greater and many lives would have been lost by the floods. Reports of families moving from the lowlands along the river front, and taking with them their stock, household furniture, etc., on the strength of the warnings issued by the Bureau were numerous, and although thousands of persons were rendered homeless during that overflow, yet the loss of life was comparatively small to what it would have been had no warnings been issued of the extreme stage expected in a given time.

It would be scarcely possible to give in a limited report full particulars of the far-reaching effects of the flood warnings; and even months in advance of the period of our usual high waters the riparian interests desire to know the Weather Bureau's opinion regarding anticipated floods, or the stage that can be expected. It is so far-reaching as to make jobbers in bagging lay in additional supplies to meet the demands of engineers, plantation owners, etc., for bags (to be filled with sand) to be used in the construction of temporary levees, and in closing crevasses, should any occur.

The detailed expression of opinion on the value of the warnings of the Bureau by the public, through the press, were forwarded to your office during the flood of 1893, and complete retained files are missing from other than city papers. The foregoing is, however, the general value of the reports as gleaned from a personal knowledge of the conditions that existed.

OMAHA, NEBR.

The business interests most affected by river conditions are corporations and companies having property located along the river, the aggregate value of which is millions of dollars, and a stage of water above the danger line would, without timely warning of its approach, cause immense loss. As the stage of the water at this point has not for years reached a point higher than 15.1 feet, which is 3 feet below the danger line, there has been no opportunity to demonstrate the value of the flood warnings in a marked manner. On April 12, 1893, and April 14, 1894, the water reached 15.1 feet, and the attention paid to the river reports and forecasts proved the faith given and the reliance placed upon the warnings and reports by those most concerned.

With reference to the river bulletin issued from this office, copies of which are furnished to all the interests affected by river conditions, a universal regret is expressed that the daily reports and changes of the river at Bismarck, Pierre, and Sioux City are not regularly published in the bulletin from April to June, inclusive, each year. This regret, while not publicly expressed, is also felt by the observer, who is seriously handicapped, at times, in making forecasts by a lack of information of the river conditions above his station.

PARKERSBURG, W. VA.

The timber and coal interests are particularly affected by the changing river conditions, and the greater of these is the timber interest. Timber and railroad ties are floated down the Little Kanawha, and the river reports indicate stages of water favorable for rafting. Knowledge of the river conditions renders it practicable for the lumber men to use the natural means of conveying their output at favorable times, and the warnings guard against surprises by floods and high water, thereby rendering comparatively safe a business which would otherwise be perilous and uncertain. Warnings of high water and floods are the means of saving merchandise piled upon the levees which would be destroyed if a flood came unannounced.

While warnings of floods are of the greatest value, warnings of even a slight rise in times of low water are of great value, as boats will often clear for up or down river points in anticipation of a small rise.

The warnings issued during the floods of February 11-17, 1893, and January 8-12, 1895, were very successful. In the former period great anxiety was felt on account of the high water. Bulletins giving the probable height beyond which the water would not rise did much to allay anxiety and evoked favorable comment from press and public. During the latter period the river conditions were constantly put before the people with equally good results.

PIERRE, S. DAK.

The highest point reached by the river in the last two years was 10 feet, April 3, 1893, the danger line being 13.1 feet. The only interest taken in the river is in times of threatened high water, as the business part of the town is nearly on a level with

the river, and merchants move goods when the water approaches the danger line during the season when the ice breaks up. The river at this point is 1 mile wide and has a great many sand bars, and the benefits resulting from this station are confined to sending telegraphic reports to Sioux City in the event of rapid rises. If reports of high water at Bismarck, or rises of 3 feet in 24 hours at that place, could be received by telegraph, they would, in the case of a flood, be the means of saving thousands of dollars' worth of property in this vicinity.

PITTSBURG, PA.

At a stage of 3 feet the river is navigable for freight and passenger packets; at 3.5 feet for towboats and empty barges; at 7 feet for loaded barges; and at 9 feet for large tows of heavy coal boats. At 20 feet traffic on the Pittsburgh and Western Railroad is suspended, and cellars in the lower portion of Allegheny City are flooded. Since 1872 a stage of 20 feet, or higher, has occurred 39 times. Twenty-five feet puts the water in the cellars of the business portion of Pittsburgh. Damage has also occurred from 22, 23, and 24 foot stages. Disastrous floods have occurred with a 27-foot stage.

Persons interested in river navigation are affected by the river conditions at all times, and merchants and persons living in the lower parts of Pittsburgh and Allegheny are affected by a stage of 20 feet, or higher. The river reports and flood warnings are of incalculable value to the river and coal operators. By means of our reports they are able to inform themselves twenty-four to thirty-six hours in advance of the probable stage of water, whether there will be sufficient for navigation, or enough to move the heavy coal boats or the lighter barges; giving them time to get their crews together and make necessary preparations. By a conservative estimate this saves to every coal firm in this vicinity shipping by river \$5,000 per year.

As an instance of the value of the flood warnings the floods of the present year may be considered. On Sunday, January 6, at 8 a. m., the stage at Pittsburgh was 2.7 feet, and rain was falling along both rivers. Special observations were called for and were received about 4 p. m. These reports showed a slight rise in the Allegheny and lower Monongahela, and a decided rise and breaking up of ice in the upper Monongahela. Warnings were immediately issued stating that the stage would be about 15 feet Monday morning. By this warning the river operators made every preparation possible to secure their fleets against damage by high water, and no losses occurred in the harbor. I am informed from reliable sources that \$100,000 worth of property was saved by this warning. The only losses in this vicinity were to the McKeesport ferryboat and the Jenkins docks in the Youghiogheny River, which were carried away; and these losses could have been averted had proper precautions been taken. At 8 a. m. of the 7th the stage of water was 12.2 feet and at 9.30 a. m. 16.5 feet. At that hour warnings were issued and telegraphed to points below, published in the newspapers, and given to interested parties by bulletin and telephone, stating the river would reach 26 feet by Tuesday morning, the 8th. As 25 to 27 feet of water floods many of the cellars in the business parts of the two cities and 30 feet many of the principal streets, this office was visited by hundreds of persons who wished to know whether their property would be damaged, and a man was kept constantly at the telephone from 10 a. m. to midnight answering inquiries. Many experienced river men predicted that a 30-foot stage would be reached, and this gave rise to many rumors of disastrous floods. Had the Allegheny River put out the volume of water it generally does, their predictions would have been verified; but this office was confident that owing to the colder climate of the Upper Allegheny Valley, caused by its elevation, and the approaching cold wave, the Upper Allegheny River would not put out much water. All persons whose interests were likely to be affected by a stage of 26 feet were advised to remove their goods; and all persons whose interests were not affected by that stage were advised to the contrary. It is estimated that property to the value of \$600,000 was saved by this warning. This rise came from

the Monongahela, Cheat, Youghiogheny, and Kiskiminitas rivers. The rivers rose rapidly during the 7th and the morning of the 8th. At 11.30 p. m. of the 7th the stage at Pittsburg was 24.4 feet, and the maximum stage, 25.8 feet, occurred at 12.45 p. m. of the 8th.

In January and February of this year extensive ice gorges formed in the Allegheny River above the mouth of the Kiskiminitas; for about 90 miles the river was nearly a solid mass of ice, in many places as high as 50 feet. These gorges were a constant menace to property, and caused great anxiety in this vicinity. Through the courtesy of the Allegheny Valley Railroad this office was informed of the movements of the gorges, and daily reports were received from Kittanning. With this information, and that received from the Weather Bureau observers, daily reports of the condition of the river and the probability of a break up were issued. As considerable alarm was manifested in this vicinity a special report was issued stating that there was no prospect of an extensive and general break up, and that no immediate danger need be apprehended. From March 21 to 25 the ice broke up and passed out without causing any damage. It is believed that the reports of the Bureau were the means of saving a large amount of property, and the work of the Bureau received much favorable comment from the public. Warnings of floods of preceding years, notably those issued in connection with the floods of February, 1891, were also the means of saving an immense amount of property.

PORTLAND, OREG.

Oregon is affected by floods from two causes: First, the Willamette freshets, which occur in February, when they do occur; and second, the June rise in the Columbia River. The former is produced by snowfalls followed by heavy warm rain; the latter by the rapid melting of the snow in the mountains of British Columbia, Washington, Montana, Idaho, and northeastern Oregon.

These floods cover the wholesale and a part of the retail business districts of Portland, causing a cessation of business; float wooden sidewalks; injure asphaltum streets; damage docks and warehouses; injure the river boat service and transportation; flood the tracks of the Northern, Union, and Southern Pacific railroads; flood mills and factories, and inundate thousands of acres in the Columbia and Willamette valleys. The largest single item of damage results from a cessation of business.

The people rely entirely upon this office for information concerning the rise and fall of the rivers and floods. The newspapers, too, rely exclusively upon this office for this information. This reliance in our reports on the part of both people and press is a measure of the value of the reports. As to the money value of the warnings, that is a difficult question to answer. Immediately after the flood of June, 1894, an estimate was obtained from 30 merchants of this city relative to the value of the reports, and this estimate placed the money value of property saved by the warnings at \$240,000. From verbal reports, newspaper expressions, etc., it would appear that our information enabled the saving of fully \$500,000 worth of property. We have labored under the disadvantage of not having gauges on the upper rivers, but this has been corrected within the last six months; and, secondly, the telegraph lines are frequently washed out just when we want reports.

During the last two years there has been but one opportunity of forecasting a flood and that was in May and June, 1894. The success attending our reports is shown by the following extract from the Portland Oregonian of June 10, 1894: "The merchants and other interested persons have relied entirely upon the Weather Bureau for information concerning the flood. Since May 21, when the river showed 18.3 feet, to June 4, the Weather Bureau has forecasted the rise. On the 4th a special bulletin was issued stating that the river would continue to rise until midnight of the 6th, it would remain stationary on the 7th, and a fall would be observable on the 8th. The prediction was verified most accurately. The Weather Bureau has

established an excellent reputation in this and adjoining States during the past few years, and all of its river information has been most thoroughly verified."

There has been no flood in the Willamette since 1890, but there have been frequent rapid rises in that river, during all of which all interested parties relied upon this office for information, and I am pleased to note that not in a single instance in the last two years has a merchant lost upon the information received from this office.

RALEIGH, N. C.

The interests affected by river conditions in North Carolina are chiefly agricultural. Low-water stages are of interest to boatmen in the larger rivers of the eastern section of the State. High-water stages are a matter of concern, first to the population along the lower river courses in localities where the banks are apt to be overflowed and crops injured or destroyed (the districts liable to overflow include narrow strips along the lower courses, averaging some 2,000 to 3,000 square miles in area, of which the greater portion lies in the low alluvial plains of the east), and in a lesser degree to farmers who pasture stock on some of the islands which appear during low water; some of these islands, notably those in the Roanoke at and below Weldon, furnish fine pasturage, but are completely submerged during high water. High-water stages also concern lumbermen and merchants in the neighborhood of the docks in some of the larger cities, particularly at Wilmington.

The establishment of the river system in North Carolina is so recent that the estimate of the value of successful warnings must be regarded as a mere approximation. If floods occur at the season when crops are ready to be gathered it is estimated that a successful warning of approaching floods would cause a saving of \$25,000 to \$50,000. After crops are gathered the warning would save from \$10,000 to \$15,000. There have been but few instances during the last two years when flood warnings were required. No warnings were issued during the high stages of August, 1893, and damage, which might in part have been avoided had warnings been issued, was caused to standing crops. The warnings of floods in October, 1893, when the river reached a stage of 42 feet at Fayetteville and 34.6 feet at Weldon, resulted in the saving of much corn and fodder. During 1894 the rivers continued low, except a local rise of the lower Cape Fear, for which no warnings were issued, and which caused some damage to crops. In 1895 very successful warnings were issued January 9 and March 20. The Cape Fear River reached the highest stage ever known at Fayetteville, 58 feet, completely verifying the warning issued of "an unusually high stage in the Cape Fear River." The Roanoke reached 41 feet at Weldon, and the warnings resulted in the saving of stock on the islands. Although in these cases crops were not endangered to any great extent, it is estimated that the warnings resulted in the saving of some \$5,000 worth of property.

RED BLUFF, CAL.

There are no interests in this immediate vicinity affected by river stages. It is only when the northern boundary of Colusa County is reached that the danger from floods along the Sacramento River begins. The land at that point, and most of the land south of there, is flat and but little above the bed of the river. Millions of dollars have been expended for protection works on this land, but owing to the soil being of a sandy nature and being infested by gophers and ground squirrels which are constantly at work boring into the levees, breaches occur occasionally when the water is high, and the land is flooded. On such occasions the damage sustained is great, for not only is the crop destroyed, but the land is rendered unfit for cultivation for two years after. The value to those localities of the river forecasts and flood warnings can not be overestimated when it is considered that by twelve hours' warning there is time before the flood arrives to repair holes in levees and otherwise put them in good order.

The writer has been informed that the timely warnings sent out by the Weather Bureau last December and January, of expected rises in the river stages, were the means of saving tens of thousands and perhaps hundreds of thousands of dollars to land owners in Colusa County alone. On December 21, 1894, the river at Red Bluff took a sudden rise. The rise was telegraphed at once to the forecast official at San Francisco. That official wired back that a dangerous rise was expected, and to warn places affected by high-river stages. The observer sent out flood warnings to points on the river as far south as Grand Island, and wired Hon. John Boggs, at Princeton, to warn his people and take necessary precautions against impending danger from flood. The result of these warnings was that the levees were strengthened before the flood wave reached the threatened localities. The highest stage of the river at Red Bluff in the last fifteen years was reached January 22, when the gauge reading was 26 feet. This rise was forecasted by the forecast official at San Francisco January 21, and the flood warnings were sent on that date by the observer at Red Bluff, with the result that little damage was done, as people were on the alert and looked after their levees.

The danger from overflow to the affected districts along the Sacramento River is increasing each year, owing to elevating causes going on in the bed of the river, and the importance of the flood warnings increase accordingly. Not only is valuable property in danger, but human life also.

SACRAMENTO, CAL.

All classes are affected, more or less, by the river during the rainy season, and towns and localities leveed against high water receive great benefit from the warnings. The old danger line at this place is 25 feet, but the levees will now stand a stage of 30 to 33 feet. The warnings are not only appreciated by people who live along the rivers, but by land owners who live in San Francisco.

ST. LOUIS, MO.

The interests most affected by river conditions are, in the order of their importance, river navigation, railroads, cotton merchants, grain receivers and shippers, and the many classes of business along the immediate river front, which are in danger of damage by overflow during flood periods.

As there have been no exceptional floods during the last two years, it is difficult to obtain much reliable data concerning the value of flood warnings during that time. It is safe to say that property to the value of \$2,000,000 which would be destroyed or damaged by flood is directly interested in the flood warnings. On May 1, 1893, one firm in this city moved to a place of safety 6,000 bales of cotton, valued at \$210,000, on the advice of the local forecast official then here, on account of the approach of high water. Another firm moved 12,000 bales, valued at \$500,000, upon the same advice, making a total of \$710,000 for one interest alone. As the water did not reach an exceptionally high stage at that time, it has been impossible to obtain any more data. During the high water of 1892 cotton valued at \$1,250,000 was moved to a place of safety on the advice of the local forecast official then here. Since May 1, 1893, there has been no occasion for flood warnings here.

ST. PAUL, MINN.

The particular interests affected are the stock yards and beef and pork houses in South St. Paul, and manufacturing establishments and store cellars on the flats of West St. Paul, all of which have been established since 1881, when the highest stage of water, 19.7 feet, was reached. Provisions were subsequently made to guard against damage from a like stage by levees and filling up the lowland, and when a stage of 13 to 14 feet is reached some inconvenience and slight damage is caused by seepage of water into cellars, etc. At stages of 11 to 14 feet numerous

small houses on the flats are flooded. The maximum stage of water in the last two years has been 14.7 feet, and no serious damage resulted, and no special flood warnings have been received during that period.

SAN FRANCISCO, CAL.

The interests affected by flood warnings in California are located principally in the Sacramento and lower portion of the San Joaquin valleys, which section is a vast level plain with but very slight difference in elevation over a vast region, amounting altogether to more than 4,000 square miles of territory. This plain is surrounded by steep mountain slopes on every side and the debris from the mountain streams has been deposited along the rivers in the valley, thus raising the surface of the valleys near the river considerably above that of the territory on either side in such a manner that when heavy rain occurs, which causes the rivers to overflow their banks, the water pours into these basins, thus overflowing a territory of about 1,500 square miles. This territory is composed of very rich alluvial land and a large portion of it has been in a measure reclaimed by building levees, and such portions are used for agricultural purposes. A large portion of this partly reclaimed land thus produces very large crops, except in seasons of unusually high water, when the levees are insufficient to protect it from the overflow.

The floods in this valley usually occur in winter or early in the spring, when heavy snow lies upon the mountains, and heavy rain occurs with warm weather and causes a rapid melting of the snow, which, together with the rainfall, greatly increases the discharge of the tributary streams. The rise in the rivers in such instances is very rapid, amounting sometimes to as much as 4 or 5 feet per hour at Red Bluff. Thus far the only information this service has received for the purpose of giving warning of floods in this valley has been from stations near the foothills just where the tributaries spread out from the canyons in the mountains into the plain of the valley, and the time limit is totally insufficient to give proper warning for points affected by the overflow, and on this account the work of this service in the past has been of slight value and has been principally confined to giving ranchers warning of the overflow, thus permitting them to remove stock and property to places of safety. The warnings sent from information received from Red Bluff last winter showed that warnings for even a slight period would be of value in permitting repairs to be made in the levees. Warnings for twenty-four and thirty-six hours in advance are possible for points from Sacramento southward. These warnings have been of marked value during the past winter, especially in one instance when high north winds were anticipated which cause rapid washing of the levees on the south side of the overflow district, which then embraced a territory 30 miles in extent. The levees thus exposed were protected by sand bags, and many places along the lower Sacramento River were probably saved from overflow thereby.

Arrangements have just been completed by which in another season reports will be obtained from points well up on the mountain slopes which will give information of rains and temperature and the rate at which snow is melting, and it is hoped that when this plan is perfected it will be possible to decidedly improve the system in various ways and give warnings at least twelve hours earlier.

SAVANNAH, GA.

Information pertaining to the Savannah River is of great importance and benefit to farmers and rice planters located along the river. During high stages they are greatly interested in the stage at Augusta, particularly the maximum stage attained at that point. It requires seven days or more for the crest of a freshet to reach Savannah after the maximum has been reached at Augusta, and farmers and rice planters have ample time to make such arrangements as they may deem necessary for the protection of their crops. The time required for the crest to reach this point, and the danger attending it, depends upon the weather conditions for several days

preceding a freshet. Should the swamps be low the freshet is slow in coming down, and the filling of the swamps diminishes the height of the freshet crest. If a freshet is preceded by a protracted wet spell reverse conditions result. It is in knowing what the weather conditions have been and what they are likely to be that enables planters to take such precautions as will best secure the safety of their crops and other property. It is not with freshets alone that planters have to contend, but also with the severe local storms that occasionally visit this section. Warnings of the storms of August 27 and 28, 1893, and of September 26 and October 9, 1894, were the means of saving many thousands of dollars to rice planters along the river adjacent to Savannah, as those who had crops in the field flooded the fields and prevented serious loss by beating winds, and rice that had been cut and stacked was secured as well as possible and suffered no serious damage.

SIOUX CITY, IOWA.

The interests most affected by the river conditions are those of the Iowa and Nebraska Pontoon Bridge Company, which has \$25,000 to \$30,000 worth of property in the bed of the Missouri River. This property can not be held against the force of floods, running ice, or even a high stage of water, and unless the company had notice of the approach of high water and secured their property along or on the banks, it would be carried down the stream and lost. The Interstate Bridge Company, formerly the Pacific Short Line Bridge Company, also has a million-dollar bridge partly completed and a large amount of property on the banks adjacent to the works. This property would be in great danger should the stage of water approach the danger line—18.7 feet.

About one-fourth of the population of the city, the principal manufactories, the large packing houses, car shops, roundhouses, and railroad switching yards are located on the flats and are exposed to danger of floods in both the Missouri and Floyd rivers. The value of these interests is very great, and it is estimated that \$75,000 to \$100,000 worth of property could be saved in that section on a twelve to twenty-four hour warning of a great flood.

A marked instance of the success of the warnings occurred March 10, 1893, when the construction company at work on the Pacific Short Line bridge had \$10,000 worth of material and machinery on its tramway to the center of the river, and were enabled by means of telegraphic reports from Bismarck, Pierre, and Yankton to remove half of this property on the approach of high water. The remainder, with half of the tramway, valued at \$5,000, was carried away. In this instance property to the value of \$5,000 was saved at a cost of not more than \$5 for telegrams.

VICKSBURG, MISS.

The agricultural interests are especially affected by the river conditions in this locality. An estimate of the value of flood warnings would be impossible, and the accuracy of the warnings is always assured in a great measure as the floods can be predicted some time in advance of their approach to the Lower Mississippi.

The flood warnings allow the planters in the bottom lands to move their stock and other property to high ground. On the other hand, when no rise in the river is indicated the planters raise a large crop on the bottom lands.

The benefits of the river reports are universal, and it would be impossible to estimate their money value for any one year. The reports are eagerly sought for by all persons whose interests are connected with the river. The daily newspapers keep the river reports and forecasts prominently before the public, and the large and constantly increasing demand for the river bulletins attest to the great interest therein.

YANKTON, S. DAK.

No flood warnings have been received during the last two years, and no estimate of their value can, therefore, be given. The principal interests affected by river conditions are the agricultural, as the flooding of farm lands would destroy crops

and property and endanger life. Public safety is affected by the possible carrying away of railroad bridges and embankments. For these reasons the flood warnings and river reports would be of great value and would be much appreciated in this vicinity.

RIVER DISTRICTS AND STATIONS.

The river and flood service was reorganized on July 3, 1893, and the duty of warning communities resident along the great rivers placed in the hands of the local forecast officials at the principal river centers. Each forecaster in charge of a river center has a definite section of the river system of his district to watch and forecast for. The information is thus more rapidly disseminated, and, being so directed as to reach those to whom it is naturally of most importance, is of more value than under any previous arrangement. Our river centers are furnished with all the data available relative to the condition of the rivers and the history of previous floods. The local forecasters, therefore, are equipped as completely as possible for the work before them, and with such advantages and their own experience and ability it is thought that no disastrous rise of the waters will occur without adequate warning of the same having been given to all concerned.

Territory is assigned as follows:

The observer at New Orleans is in charge of forecasts for the Mississippi River from below Vicksburg, the Red and the Ouachita rivers; the observer at Vicksburg takes charge of the river from Memphis to Vicksburg; the observer at Memphis, the St. Francis River and the Mississippi at Memphis; the observer at Cairo takes that section of the Ohio from Evansville to Cairo and the Mississippi from below St. Louis to Memphis; the observer at St. Louis takes charge of the Mississippi from Davenport to St. Louis and the Missouri east of Kansas City; the observer at Omaha takes the Missouri from Kansas City northward; the observer at Cincinnati takes the Ohio and its tributaries from Evansville to Marietta, and the observer at Pittsburg the Ohio and its tributaries above Marietta, while the Cumberland is watched from Nashville and the Tennessee from Chattanooga; the rivers in Alabama are watched from Montgomery; in North Carolina, from Raleigh; in South Carolina, from Charleston; the Arkansas, from Little Rock; the Mississippi above Davenport, from Davenport; the Susquehanna, from Harrisburg; the James, from Richmond; the Potomac, from Washington; the Savannah, from Augusta; the Snake, Willamette, and Columbia rivers, from Portland, Oreg., and the Sacramento and San Joaquin, from San Francisco.

The stations may be grouped as follows:

Stations making forecasts daily of the river conditions: Cairo, Chattanooga, Cincinnati, Davenport, Memphis, Nashville, New Orleans, Pittsburg, St. Louis, and Vicksburg.

When floods are imminent, in addition to the above stations, the observers at Augusta, Harrisburg, Albany, Raleigh, Little Rock, Mobile, Montgomery, Atlanta, Washington, San Francisco, Omaha, Portland, Richmond, and Charleston make forecasts of the river conditions.

List of special river stations.

Station.	River.	Reports to—
Albany, Ga.	Flint	Atlanta.
Albany, Oreg.	Willamette	Portland, Oreg.
Alexandria, La.	Red	New Orleans.
Arkadelphia, Ark.	Washita	Do.
Arkansas City, Ark.	Mississippi	Vicksburg.
Arlington, Mo.	Gasconade	St. Louis.
Arthur City, Tex.	Red River	New Orleans.
Bagnell, Mo.	Osage	St. Louis.
Bainbridge, Ga.	Flint	Atlanta.
Bayou Sara, La.	Mississippi	New Orleans.
Beardstown, Ill.	Illinois	St. Louis.
Beaver Dam, Pa.	Ohio	Pittsburg.
Bismarck, N. Dak.	Missouri	Bismarck.
Bluff City, Tenn.	Holston	Chattanooga.
Boonville, Mo.	Missouri	St. Louis.
Brookville, Pa.	Red Bank	Pittsburg.
Buchanan, Va.	James	Lynchburg.
Burnside, Ky.	Cumberland	Nashville.
Camden, Ark.	Ouachita	New Orleans.
Camden, S. C.	Wateree	Charleston.
Canton, Ga.	Etowah	Atlanta.
Carthage, Tenn.	Cumberland	Nashville.
Catlettsburg, Ky.	Ohio	Cincinnati.
Charleston, Tenn.	Hiwassee	Chattanooga.
Charleston, W. Va.	Great Kanawha	Cincinnati.
Chester, Ill.	Mississippi	Cairo.
Cheraw, S. C.	Pedee	Charleston.
Circleville, Ohio	Scioto	Cincinnati.
Claiborne Landing, Ala.	Alabama	Montgomery.
Clarksville, Va.	Roanoke	Raleigh.
Clarion, Pa.	Clarion	Pittsburg.
Clinton, Tenn.	Clinch	Chattanooga.
Columbia, Tenn.	Duck	Cairo.
Columbus, Ga.	Chattahoochee	Atlanta.
Columbus, Miss.	Tombigbee	Montgomery.
Confluence, Pa.	Youghiogheny	Pittsburg.
Conway, S. C.	Waccamaw	Charleston.
Cordova, Ala.	Big Warrior	Montgomery.
Coushatta, La.	Red	New Orleans.
Danville, Va.	Dan	Raleigh.
Dardanelle, Ark.	Arkansas	Little Rock.
Davis Island Dam, Pa.	Ohio	Pittsburg.
Dayton, Ohio	Miami	Cincinnati.
Delhi, La.	Bayou Macon	New Orleans.
Demopolis, Ala.	Tombigbee	Montgomery.
Donaldsonville, La.	Mississippi	New Orleans.
Dublin, Ga.	Oconee	Atlanta.
Eddyville, Ky.	Cumberland	Cairo.
Edisto, S. C.	Edisto	Charleston.
Effingham, S. C.	Lynche's River	Do.
Elwood Junction, Pa.	Beaver	Pittsburg.
Eufaula, Ala.	Chattahoochee	Atlanta.
Eugene City, Oreg.	Willamette	Portland, Oreg.
Fair Bluff, N. C.	Lumber	Charleston.
Fairmont, W. Va.	Monongahela	Pittsburg.
Falmouth, Ky.	Licking	Cincinnati.
Fayetteville, N. C.	Cape Fear	Raleigh.
Florence, Ala.	Tennessee	Cairo.
Freeport, Pa.	Allegheny	Pittsburg.
Fulton, Ark.	Red	New Orleans.
Gadsden, Ala.	Coosa	Montgomery.
Grafton, Ill.	Mississippi	St. Louis.
Greensboro, Pa.	Monongahela	Pittsburg.
Greenville, Miss.	Mississippi	Vicksburg.
Harpers Ferry	Potomac	Washington.

List of special river stations—Continued.

Station.	River.	Reports to—
Helena, Ark.	Mississippi	Vicksburg.
Hermann, Mo.	Missouri	St. Louis.
Hinton, W. Va.	New	Cincinnati.
Johnsonville, Tenn.	Tennessee	Cairo.
Johnstown, Pa.	Stony Creek	Pittsburg.
Kingston, Tenn.	Clinch	Chattanooga.
Kingstree, S. C.	Black	Charleston.
Kleinston, Miss.	Mississippi	Vicksburg.
Lafayette, Ind.	Wabash	Cairo.
Leclaire, Iowa	Mississippi	Davenport.
Lockhaven, Pa.	Susquehanna	Harrisburg.
Lock No. 4, Pa.	Monongahela	Pittsburg.
Loudon, Tenn.	Holston	Chattanooga.
Louisa, Ky.	Big Sandy	Cincinnati.
Louisiana, Mo.	Mississippi	St. Louis.
Lewiston, Idaho	Clearwater	Portland, Oreg.
Little Dallas ¹		
Macon, Ga.	Ocmulgee	Atlanta.
Mahoning, Pa.	Allegheny	Pittsburg.
Marietta, Ohio	Ohio	Cincinnati.
Melville, La.	Atchafalaya	New Orleans.
Monroe, La.	Onachita	Do.
Morgantown, W. Va.	Monongahela	Pittsburg.
Mount Carmel, Ill.	Wabash	Cairo.
Mount Vernon, Ind.	Ohio	Do.
Muscatine, Iowa	Mississippi	Davenport.
Natchez, Miss.	do	New Orleans.
Newport, Ark.	White	Vicksburg.
Northport, Wash.	Columbia	Portland, Oreg.
North McGregor, Iowa	Mississippi	Davenport.
Oil City, Pa.	Allegheny	Pittsburg.
Paducah, Ky.	Ohio	Cairo.
Parker, Pa.	Allegheny	Pittsburg.
Peoria, Ill.	Illinois	St. Louis.
Philippi, W. Va.	Tygarts Valley Creek	Pittsburg.
Plattsmouth, Nebr.	Missouri	Omaha.
Point Pleasant, W. Va.	Ohio	Cincinnati.
Portsmouth, Ohio	do	Do.
Radford, Va.	New	Do.
Reeds Landing, Minn.	Mississippi	Davenport.
Red Wing, Minn.	do	Do.
Resaca, Ga.	Oostanaula	Atlanta.
Reynolds, Ga.	Flint	Do.
Richmond, Va.	James	Lynchburg.
Rockwood, Tenn.	Tennessee	Chattanooga.
Rome, Ga.	Coosa	Atlanta.
Rowlesburg, W. Va.	Cheat	Pittsburg.
St. Joseph, Mo.	Missouri	Omaha.
St. Paul, Minn.	Mississippi	St. Paul.
St. Stephens, S. C.	Santee	Charleston.
Salem, Oreg.	Willamette	Portland, Oreg.
Saltsburg, Pa.	Kiskiminitas	Pittsburg.
Selinsgrove, Pa.	Susquehanna	Harrisburg.
Selma, Ala.	Alabama	Montgomery.
Speers Ferry, Va.	Clinch	Chattanooga.
Spokane, Wash.	Spokane	Portland, Oreg.
Stoyestown, Pa.	Conemaugh	Pittsburg.
Strawberry Plains, Tenn.	Holston	Chattanooga.
Sturdevant, Ala.	Tallapoosa	Montgomery.
Tallassee Falls, Ala.	do	Do.
Terre Haute, Ind.	Wabash	Cairo.
The Dalles, Oreg.	Columbia	Portland, Oreg.
Towanda, Pa.	Susquehanna	Harrisburg.

¹ See Northport, Wash.

List of special river stations—Continued.

Station.	River.	Reports to—
Tuscaloosa, Ala	Black Warrior	Montgomery.
Umatilla, Oreg	Columbia	Portland, Oreg.
Warren, Pa	Allegheny	Pittsburg.
Warsaw, Ill	Mississippi	St. Louis.
Weiser, Idaho	Snake	Portland, Oreg.
Weldon, N. C.	Roanoke	Raleigh.
Wenatchee, Wash	Columbia	Portland, Oreg.
West Newton, Pa	Youghiogeny	Pittsburg.
Weston, W. Va	West Fork Monongahela.	Do.
Wetumpka, Ala	Coosa	Montgomery.
Wheeling, W. Va	Ohio	Pittsburg.
Whitesburg, Ga	Chattahoochee	Atlanta.
Wilkesbarre, Pa	Susquehanna	Harrisburg.
Wilsonville, Ala	Coosa	Montgomery.
Wittsburg, Ark	St. Francis	Memphis.
Yazoo City, Miss	Yazoo	Vicksburg.
Zanesville, Ohio	Muskingum	Cincinnati.

THE SYSTEM OF FLOOD WARNINGS.

There are now (January 1, 1896) in active operation 135 special river stations, 44 rainfall stations, and 38 regular river stations. The special work of the Weather Bureau in connection with the rivers of the country is to save life and property by giving timely warning of floods.

As yet the rules for flood forecasting are largely empirical. The observer in charge of any river center is, or ought to be, familiar with the main river and the tributaries, the area of the catchment basin and its topography, the frequency and the intensity of the rainfall, especially the intensity, the average time of passage of the flood crest between one station and another, and the history of past rises. Knowledge of low-water conditions, especially where bars and shoals exist, is perhaps of equally great importance as the knowledge of high water. Constant representations are made by steamboat and navigation interests that low-water conditions continue longer and affect navigation more. The observer is often able, with the means already referred to, to give the desired information; but his chief and foremost duty, in view of the fact that river improvements and measurements are otherwise provided for, is the dissemination of warnings when floods threaten.

RECORDS OF RIVER STAGES.

Records of river stages have been published as follows:

"Regular gauge histories," including readings on the Missouri River gauges from 1872 to 1886, both inclusive. Issued by the Missouri River Commission.

"Stages of the Mississippi River from Cairo to Carrollton, preliminary to stages of the Mississippi and its tributaries," including readings from 1871 to 1886, both inclusive. Issued by the Mississippi River Commission.

"Stages of the Mississippi River above Cairo and of the tributaries of the Mississippi River, except the Missouri River," including readings from 1871 to 1886, both inclusive. Issued by the Mississippi River Commission, 1889.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1887 and 1888." Compiled at the secretary's office, Mississippi River Commission, 1889.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri, for 1889." Compiled at the secretary's office, Mississippi River Commission, 1890.

"Missouri River Commission. Stages of the Missouri River from St. Charles, Mo., to Sioux City, Iowa." Compiled from miscellaneous and regular gauge records, 1886 to 1889, both inclusive. Mississippi River Commission print, 1890.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1891." Mississippi River Commission, 1892.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1892." Mississippi River Commission, 1893.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1893." Mississippi River Commission, 1894.

"Stages of the Ohio River and of its principal tributaries, 1858 to 1889, inclusive." Part I. Washington City, Signal Office, 1890.

"Stages of the Mississippi River and of its principal tributaries, except the Ohio River, 1860 to 1889, both inclusive." Part II. Washington City, Weather Bureau Office, 1891.

"Stages of water at miscellaneous river stations in California, Oregon, North Carolina, etc., 1875 to 1889, both inclusive." Part III. Washington City, Weather Bureau Office, 1891.

"Daily river stages at river-gauge stations on the principal rivers of the United States for the years 1890-1892." Part IV. Weather Bureau, 1893.

Report of the Chief Signal Officer, 1891, pages 67 to 260.

Report of the Chief of the Weather Bureau, 1891-92, pages 483 to 504.

From the data thus collected, covering now many years at some stations and shorter periods at others, the following general relations have been deduced:

The time it takes high water to pass from Pittsburg to Wheeling is one day; from Pittsburg to Parkersburg, two days; from Parkersburg to Cincinnati, three days; from Cincinnati to Cairo, six days; from Cairo to Vicksburg, seven days, and from Vicksburg to New Orleans, four days. From Pittsburg, therefore, to the Gulf requires twenty-two days. Since the time of travel is so great, it naturally follows that many interfering conditions arise tending to accelerate or retard the crest of the flood wave. No simple time rules are, therefore, possible.

The volume of water passing any given station in a given time is known only for a few places, and varies, of course, with high and low water. Nor can simple rules be based upon the rainfall, as the distribution over the drainage area is not always determinable.

Omitting for the present the rainfall relations, we find the following general relations concerning the movement of the water:

TABLES OF DISTANCES, RIVER TRIBUTARIES, AND RATE OF FLOOD MOVEMENT.

Beginning with the head of navigation on the Mississippi, St. Paul, Minn., we have the following:

	Distance by river channel from—		Number of days it takes high water to pass between stations.	Number of days to pass from station to Cairo.
	Gulf.	Cairo.		
Mississippi River:	<i>Miles.</i>	<i>Miles.</i>		
(1) St. Paul.....	2,057	917		9
(2) Red Wing.....	1,998	858		8½
(3) Reeds Landing.....	1,966	826		8
(4) La Crosse.....	1,867	727		7½
(5) North McGregor.....	1,819	679		7
(6) Dubuque.....	1,759	619		6½
(7) Leclaire.....	1,669	529	1	5
(8) Davenport.....	1,653	513	1	5
(9) Muscatine.....	1,622	482	1	5
(10) Keokuk.....	1,523	383	1	4
(11) Warsaw.....	1,518	378	1	4
(12) Quincy.....	1,482	342	1	3½
(13) Hannibal.....	1,462	322	1	3
(14) Louisiana, Mo.....	1,433	283	1	3
(15) St. Louis.....	1,321	181	1	2
(16) Cape Girardeau.....	1,183	43	1½	2
(17) Cairo (on the Ohio, 1 mile from mouth).....	1,140		1½	1½
(18) Memphis.....	910	230	2	1½
(19) Helena.....	834	306	1	1½
(20) Arkansas City.....	702	458	1	1½
(21) Greenville.....	662	478	1	1½
(22) Vicksburg.....	541	599	2	1½
(23) Kleinston.....	536	604	2	1½
(24) Bayou Sara.....	340	800	2	1½
(25) New Orleans.....	108	1,032	2	1½

¹ Number of days from station to mouth of river.

Yazoo.—Yazoo City, Miss., 65 miles to mouth of river; time of movement of water from station to mouth of river, two-thirds of a day.

St. Francis.—Wittsburg, Ark., 180 miles, and two and one-fourth days.

Illinois.—Beardstown, Ill., 76 miles from station to mouth of river; time, one day. Peoria, Ill., 141 miles; time, two days.

Des Moines.—Des Moines, Iowa, 175 miles; time, two days.

White.—Newport, Ark., 175 miles to Arkansas City (877 miles to Gulf); time, two days.

	Distance by river channel from—		Movement to Cairo.	Movement between stations.
	Gulf.	Cairo.		
Ohio River:	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>	<i>Days.</i>
Pittsburg.....	2,105.5	985.5	11	.....
Davis Island Dam.....	2,100	980	10½	.....
Wheeling, W. Va.....	2,015	875	10	.....
Marietta.....	1,935	795	9½	.....
Parkersburg.....	1,925	785	9	.....
Point Pleasant.....	1,843	703	8½	.....
Catlettsburg.....	1,791	651	7½	.....
Portsmouth.....	1,752	612	7½	.....
Cincinnati.....	1,639	499	5½	1½
Louisville.....	1,507	367	4½	1½
Evansville.....	1,324	184	2	2½
Mount Vernon.....	1,288	148	1½	2½
Paducah.....	1,187	47	½	1½
Cairo.....	1,141	1	.....	.....

	Distance from—			Movement to—	
	Gulf.	Cairo.	The Ohio.	The Ohio.	Cairo.
Wabash:	<i>Miles.</i>	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>	<i>Days.</i>
Lafayette.....	1,468	326	198	2½	4½
Mount Carmel.....	1,318	178	50	¾	2
Terre Haute.....	1,408	268	140	1½	3½
Miami:					
Dayton, Ohio.....	1,695	555	69	¾	6½
Licking:					
Falmouth, Ky.....	1,669	529	30	½	6½
Scioto:					
Circleville, Ohio.....	1,817	677	65	¾	8
Big Sandy:					
Louisa, Ky.....	1,816	676	26	½	7½
Great Kanawha:					
Charleston, W. Va.....	1,904	764	61	¾	8½
Hinton, W. Va.....	1,999	859	156	1½	10
Radford, Va.....	2,049	909	206	2½	11
Muskingum:					
Zanesville, Ohio.....	2,000	860	65	¾	10
Beaver:					
Elwood Junction.....	2,092	952	12	¾	10½
Allegheny:					
Warren, Pa.....	2,272	1,132	167	2	13
Oil City, Pa.....	2,218	1,078	113	1½	12½
Parker, Pa.....	2,178	1,038	73	¾	12
Mahoning, Pa.....	2,155	1,015	50	¾	11½
Freeport, Pa.....	2,131	991	26	¾	11½
Pittsburg, Pa.....	2,105	965	.....	.....	11

The Allegheny and Monongahela form the Ohio at Pittsburg. The Kiskiminetas, Red Bank, and Clarion are tributaries of the Allegheny.

	Distance from—				Movement to—	
	Gulf.	Cairo.	Pittsburg.	Allegheny.	The Ohio.	Cairo.
Kiskiminetas:	<i>Miles.</i>	<i>Miles.</i>	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>	<i>Days.</i>
Salisbury, Pa.....	2,153	1,013	48	22	¾	11½
Red Bank:						
Brookville, Pa.....	2,196	1,056	91	30	1	12
Clarion:						
Clarion, Pa.....	2,202	1,062	97	19	1	12
Stony Creek:						
Johnstown, Pa.....	2,220	1,031	90	64	1	12½
Stoyestown, Pa. ¹.....	.....	.....	.....	.....	.....	.....

¹ About 15 miles south of Johnstown, on the Conemaugh.

Tygarts Valley River, Cheat, and Youghiogheny empty into the Monongahela.

	Distance from—			Movement to—	
	Gulf.	Cairo.	The Ohio.	The Ohio.	Cairo.
Monongahela:	<i>Miles.</i>	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>	<i>Days.</i>
Weston, W. Va.....	2, 286	1, 126	181	2	2
Fairmont, W. Va.....	2, 224	1, 085	119	1½	12½
Morgantown, W. Va.....	2, 200	1, 060	95	1½	12
Greensboro, Pa.....	2, 186	1, 046	81	1	12
Lock No. 4, Pa.....	2, 145	1, 005	40	½	11½
	Distance from—			Movement to—	
	Gulf.	The Ohio.	The Monongahela.	The Ohio.	Cairo.
Tygarts Valley River:	<i>Miles.</i>	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>	<i>Days.</i>
Philippi, W. Va.....	2, 260	155	36	1½	12½
Cheat:					
Rowlesburg, W. Va.....	2, 226	121	40	1½	12½
Youghiogheny:					
West Newton, Pa.....	2, 136	31	10	½	11½
Confluence, Pa.....	2, 180	75	65	1½	11½

	Distance from—		Movement to Cairo.	Distance by river—		Movement from station to mouth of river.
	Gulf.	Cairo.		From Cairo.	To mouth of river.	
Tennessee:	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>
Knoxville, Tenn.....	1, 781	640	7	680	640	7
Loudon, Tenn.....	1, 723	582	6½	624	582	6½
Rockwood, Tenn.....	1, 685	544	5½	584	544	5½
Chattanooga, Tenn.....	1, 596	455	5	495	455	5
Florence, Ala.....	1, 361	220	3	266	220	3
Johnsonville, Tenn.....	1, 235	94	1½	140	94	1½

The Duck, Hiwassee, Clinch, and Holston empty into the Tennessee.

	Distance to mouth of river.	Time to mouth of river.
Duck:	<i>Miles.</i>	<i>Days.</i>
Columbia, Tenn.....	70	1
Hiwassee:		
Charleston, Tenn.....	18	½
Clinch:		
Kingston, Tenn.....	5	½
Clinton, Tenn.....	51	½
Speers Ferry, Va.....		
Holston:		
Strawberry Plains, Tenn.....	20	½
Bluff City (South Fork), Tenn.....		

The Cumberland empties into the Ohio.

	Distance from—		Time to mouth of river.
	Cairo.	Mouth of river.	
Cumberland:	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>
Burnside, Ky.....	474	404	5
Carthage, Tenn.....	297	227	2½
Nashville, Tenn.....	215	145	1½
Eddyville, Ky.....		30	½

The Arkansas empties into the Mississippi.

	Distance from—		Time to mouth of river.
	Gulf.	Mouth of river.	
Arkansas:	<i>Miles.</i>	<i>Miles.</i>	<i>Days.</i>
Fort Smith, Ark.	1,095	351	4
Dardanelle, Ark.	1,000	256	2½
Little Rock, Ark.	920	176	2

	Distance by river channel to mouth of river.	Time to mouth of river.		Distance by river channel to mouth of river.	Time to mouth of river.
The Missouri:	<i>Miles.</i>	<i>Days.</i>	The Shenandoah:	<i>Miles.</i>	<i>Days.</i>
Fort Buford, Mont.	1,663	.....	Riverton, Va.	45	½
Bismarck, N. Dak.	1,327	.....	The Susquehanna:		
Pierre, S. Dak.	1,132	.....	Towanda, Pa.	256	3
Yankton, S. Dak. ....	.....	.....	Wilkesbarre, Pa.	181	2½
Sioux City, Iowa	802	8	Selinsgrove, Pa.	117	1½
Omaha, Nebr.	667	6½	Harrisburg, Pa.	72	1
Plattsmouth, Nebr.	639	6½	West Branch of Susquehanna:		
St. Joseph, Mo.	479	5	Lock Haven, Pa.	65	1
Kansas City, Mo.	386	4	The Atchafalaya:		
Boonville, Mo.	197	2½	Melville, La.	96	1½
Hermann, Mo.	101	1½	The Red:		
The Gasconade:			Arthur City, Tex.	799	10
Arlington, Mo.	65	1	Fulton, Ark.	676	8
The Osage:			Shreveport, La.	449	5½
Bagnell, Mo.	65	1	Coushatta, La.	299	3½
The James:			Alexandria, La.	139	1½
Lynchburg, Va.	251	3	The Ouachita:		
Richmond, Va.	104	1½	Camden, Ark.	485	6
Buchanan, Va.	99	1	Monroe, La.	271	3½
Savannah:			Bayou Beuf:		
Augusta, Ga. ....	.....	.....	Girard, La.	245	3
Potomac:			Bayou Macon:		
Harpers Ferry, W. Va.	164	2	Dellui, La.	275	3½
Washington, D. C.	104	½			

The Etowah and Oostanaula form the Coosa; the Coosa and Tallapoosa form the Alabama; the Locust and Mulberry forks form the Black Warrior, which empties into the Tombigbee; the Alabama and the Tombigbee form the Mobile.

	Distance by water to mouth of river.	Time to mouth of river.		Distance by water to mouth of river.	Time to mouth of river.
The Alabama:	<i>Miles.</i>	<i>Days.</i>	The Oostanaula:	<i>Miles.</i>	<i>Days.</i>
Montgomery, Ala.	215	2½	Resaca, Ga.	30	½
Selma, Ala.	117	1½	The Etowah:		
Clairborne, Ala.	45	½	Canton, Ga.	55	½
The Coosa:			The Tombigbee:		
Wilsonville, Ala.	75	1	Columbus, Miss.	295	3½
Gadsden, Ala.	135	1½	Demopolis, Miss.	135	1½
Rome, Ga.	216	2½	The Black Warrior:		
The Tallapoosa:			Tuscaloosa, Ala.	131	1½
Sturdevant, Ala.	54	½	Mulberry Fork of Black Warrior:		
Tallapoosa, Ala.	20	½	Cordova, Ala.	50	½

The Sacramento and San Joaquin drain the Great Central Valley of California into Suisun Bay, the former bringing its water from the north, the other from the south. Karquines Strait connects Suisun Bay to San Pablo Bay and San Francisco Bay.

THE SACRAMENTO.

Its tributaries are the Feather, Butte Creek, Table Mountain Creek, Chico Pine, Dry Deer, Mud, Little Antelope, Big Antelope, and Salt.

THE SAN JOAQUIN.

Main tributaries are the Calaveras, Tuolumne, Orestimba, Merced, Fresno, and Kings River Slough.

THE COLUMBIA.

Main tributaries are the Willamette, in western Oregon; the Snake, in Idaho; the Kootenai, in Montana, and Lake Pend Oreille, in northern Idaho.

	Distance from Portland.
The Columbia:	Miles.
Northport.....	569
Wenatchee.....	359
Umatilla.....	187
The Snake:	
Weiser.....	427
Lewiston.....	393

NOTES ON RIVERS AND FLOODS.

The following notes on rivers and floods are furnished by Weather Bureau officials in charge of river stations:

ALBANY, N. Y.

By Mr. A. F. SIMS, *Observer*.

The fountain head of the Hudson River is a small pool on the southern slope of Mount Marcy, 4,326 feet above the sea, and known as Summit Lake, Summit Water, or Lake Tear of the Clouds.

The Hudson River from its source to its mouth lies within the deep valley which terminates the eastern table-land of the Appalachian system. On its watershed are mountain chains more or less isolated from each other and bearing the highest summits in the State. They are the Highlands, which cross the Hudson at the limit of the coast region; Shawangunk and Catskill Mountains on the western bank of the river, and the system of the Adirondacks covering the territory between the St. Lawrence and Champlain valleys.

The Hudson Valley region is a long, narrow strip of land on both sides of the Hudson, surrounded first by hills and low table-lands as far as the gorges, where the river crosses the Highlands.

The valley widens higher up into the extensive plains on the eastern side of the river.

Notwithstanding this low situation, its climate is severe, owing to the cold northern winds which blow from Canada and Labrador along the open valley of Lake Champlain.

The Mohawk Valley is a deep transversal cut; its river is the principal feeder to the Hudson north of Albany.

The principal water power in Albany County is supplied by the Mohawk River at Cohoes, N. Y. The Mohawk is about 175 miles long and drains a territory which is on an average 20 miles wide. The total drainage area is thus about 3,500 square miles.

The average volume of the Hudson at Albany, N. Y., is estimated to be 618,111 cubic feet per minute, equal to an average daily flow of 6,677,000,000 gallons, the minimum being 1,829,000,000 in July, and the maximum 12,330,000,000 in March.

AUGUSTA, GA.

By Mr. D. FISHER, *Observer.*

The following rain-reporting stations are now in operation in the up river country: Anderson, S. C., established January 13, 1892; Elberton, Ga., established December 1, 1891; Greenwood, S. C., established December 1, 1892; Mount Carmel, S. C., established January 13, 1892; Toocoa, Ga., established December 1, 1891; Washington, Ga., established December 1, 1891.

When the river is 10 feet or lower, the following average of rain throughout the upper valley will give a river as indicated below:

Inches of rain required in a given number of hours to produce different stages of the river.

Rainfall.	Number of hours.	Stage of river.	Rainfall.	Number of hours.	Stage of river.
<i>Inches.</i>		<i>Feet.</i>	<i>Inches.</i>		<i>Feet.</i>
1.50	24	20.0	4.50	48	30.5
2.00	24	24.0	5.00	48	31.5
2.50	24	26.0	5.50	48	32.0
3.00	24	28.0	6.00	48	33.5
3.50	24	30.0	6.50	48	34.5
4.00	24	31.5	7.00	48	35.5
4.50	24	32.5	1.50	72	16.0
5.00	24	33.5	2.00	72	20.0
5.50	24	34.5	2.50	72	22.0
6.00	24	35.5	3.00	72	24.0
6.30	24	36.5	3.50	72	26.0
7.00	24	37.5	4.00	72	27.5
1.50	48	18.0	4.50	72	28.5
2.00	48	22.0	5.00	72	29.5
2.50	48	24.0	5.30	72	30.5
3.00	48	26.0	6.00	72	31.5
3.50	48	28.0	6.30	72	32.5
4.00	48	29.5	7.00	72	33.5

Discharge of the river at various stages.

	Cubic feet.
30 feet.....	89,000
35.1 feet.....	155,000
40.1 feet.....	370,000

Area of watershed above Augusta, 7,294 square miles. The above data were determined by myself after careful consideration of all facts and from surveys in 1888 and 1889, and are believed to be substantially correct, conflicting statements to the contrary notwithstanding.

[Correction by Mr. George W. Brown, civil engineer office, Florence, Ala.]

Height of zero of gauge above mean low water, Savannah, Ga., 103.82 feet; low water on gauge (since 1888), 5.8; highest water known, 38.7 feet (September 11, 1888); low water flow at Augusta, 3,800 cubic feet per second; high water discharge at Augusta (September 11, 1888), 305,000 cubic feet per second.

The following table shows the discharge of the river at Augusta, Ga., for various heights on the gauge (since 1888):

Height of river.	Discharge per second.	Height of river.	Discharge per second.
<i>Feet.</i>	<i>Cubic feet.</i>	<i>Feet.</i>	<i>Cubic feet.</i>
5	3,000	14	20,000
6	4,000	15	22,700
7	5,210	16	25,500
8	6,600	17	28,700
9	8,400	18	32,100
10	10,400	19	35,500
11	12,600	20	39,000
12	14,900	25	60,000
13	17,300		

ATLANTA, GA.

By Mr. GEORGE E. HUNT, *Local Forecast Official.*

Eight streams comprise the system of rivers under the regimen of the Atlanta station, viz: The Oostanaula, Etowah, Coosa, Chattahoochee, Flint, Ocmulgee, Oconee, and Altamaha.

The total length of these rivers aggregates about 1,600 miles; the total navigable length of all of them is about 800 miles, as follows:

Altamaha, length, 70 miles; navigable, 70 miles; basin area, including that of its two confluent, the Ocmulgee and Oconee, about 14,000 square miles.

Ocmulgee, length, 300 miles; navigable, 40 miles.

Oconee, length, 300 miles; navigable, 40 miles.

Chattahoochee, length, 450 miles; navigable, 300 miles; its basin area is about 6,900 square miles.

Flint, length, 300 miles; navigable, 250; basin area, about 9,500 square miles.

Etowah, length, about 100 miles; not navigable.

Oostanaula, navigable about 80 miles; the drainage area of the Oostanaula and Etowah combined is about 3,700 square miles.

To properly understand the above streams a glance at a topographical map of the State is necessary. A great ridge of hills or low mountains passes from north to south almost centrally through Georgia. This is a part of the long, irregular eastern edge of the great Mississippi Basin. A second ridge separates the Mississippi Valley from the Gulf Slope. This, the southern edge of the Mississippi Basin, also passes through the northern portion of Georgia, the two ridges meeting in the northeast corner of the State. It is said that at this critical point an umbrella held in a shower of rain sheds the water so that one part reaches the Atlantic near Savannah, a second part the Gulf at Apalachicola, while a third enters the Gulf below New Orleans, having passed through the Hiwassee, Tennessee, Ohio, and Mississippi rivers. It is thus seen that Georgia participates in three great basins, determined by the ridges of watersheds just described. Of her surface there are in the Atlantic Slope about 32,000 square miles, the Gulf Slope about 25,700 square miles, and the Mississippi Valley about 850 square miles, over one-half of her surface drainage flowing into the Atlantic.

The Coosa River, in the extreme northwest portion of the State, is formed at Rome by the junction of the Oostanaula and Etowah rivers, and flows due westward into Alabama, traversing but a single county in Georgia. The confluent of the Coosa, having the mountains of eastern Tennessee and north Georgia for watersheds, flow down almost as from the apex of a cone, and draining, as at least one of them does, a portion of north Georgia subject to an annual rainfall of over 60 inches, causes Rome to be the point most exposed to flood damage of all places in Georgia. In addition to the gauge at Rome this service has one on the Oostanaula, at Resaca, 30 miles above Rome, and another on the Etowah, at Canton, 48 miles above Rome. Rains

at the head waters or along these streams affect the Coosa at Rome within twenty-four hours, and the maximum rise resulting from them usually occurs within forty-eight hours. It appears, from an examination of all the accessible data, that rises in the Oostanaula are more sudden than those in the Etowah, and that they reach Rome slightly in advance of those in the latter river. On December 26, 1894, heavy rains fell at voluntary State weather service stations located near the head waters of the Oostanaula. On the morning of that date the river at Resaca stood 2.1 feet on the gauge, and the Coosa at Rome 1.6 feet. By the morning of the 27th the Oostanaula had risen 11 feet at Resaca, and the Coosa 7 feet at Rome. By the morning of the 28th there was a further rise of 3 feet at Rome, while at Resaca the Oostanaula had begun to fall. During the period of the above changes in the Oostanaula the rise in the Etowah amounted to only 1 foot. This, however, is a very rare occurrence, both rivers usually rising at or near the same time as to make little difference in the effects of such rises upon the Coosa at Rome. In fact, in no instance do the records at this office show a rise of any consequence in one of these streams without a corresponding rise in the other. Their head waters are not very far apart, but while the Oostanaula flows almost due southward, the Etowah makes a grand sweep southward, after which it flows westerly, its course resembling somewhat an immense horseshoe. On the 9th and 10th of December, 1894, voluntary observers about the head waters and along both streams reported heavy rains. By the morning of the 29th the Oostanaula had risen over 9 feet at Resaca; the Etowah, at Canton, 6 feet 5 inches, and the Coosa, at Rome, 12 feet 4 inches. On the morning of the 13th the crest of the freshet had reached Rome, causing a further rise of 2 feet 6 inches in the Coosa at that point.

The Chattahoochee River has its source in the mountains of north central Georgia, flowing for the first hundred miles or over in a southwesterly direction along a narrow valley with mountainous watersheds on each side. From a point nearly due west from Atlanta its valley widens out to the east, the mountains on that side receding and dwindling into low hills, but on the west side its valley continues narrow, the river hugging the base of the mountains for a considerable distance farther south. Freshets occurring in the river north of Atlanta do but little damage, the valley being narrow and containing but little arable land. For quite a long stretch between Atlanta and the Alabama line the country along the river is flat and subject to damaging floods. It should be remembered that the Chattahoochee is the boundary line between the States of Alabama and Georgia for a distance of about half the length of the two States. From the Alabama line to Columbus, a distance of about 30 miles, there is a fall of 362 feet, making the river dangerous at and just below the latter place. This service has three gauges on the Chattahoochee; the first at Whitesburg, about 40 miles below a point 7 miles due west of Atlanta; the second at Columbus, 80 miles below Whitesburg; and the third at Eufaula, Ala., about 50 miles below Columbus. Rains at Atlanta and along the water sheds north of that city cause a rise at Whitesburg within from sixteen to twenty-four hours, and the crest of the freshet always passes from Whitesburg to Columbus within less than twenty-four hours, and from Columbus to Eufaula in considerable less time than twenty-four hours. The river seldom overflows its banks in the vicinity of Eufaula, but damaging floods occur both above and below that place.

The Flint River rises in western Georgia, just south of the source of the Chattahoochee, emptying into the latter stream in the extreme southwest corner of the State. This service has three gauges on the Flint, the first being at Reynolds, a point located about 100 miles south of its source, the second at Albany, 80 miles below Reynolds, and a third at Bainbridge, 60 miles below Albany. Rains about the headwaters of the Flint affect the gauge readings at Reynolds within twenty-four hours, but from that point to Albany the current is sluggish, and the crest of a freshet is generally two days in passing to Albany, and much longer than that when the floods are very high. There is no instance on record when the maximum effects

of a freshet were noted at Albany within less than four days after being reported at Reynolds. The crest of a freshet is about twenty-four hours in passing from Albany to Bainbridge.

The Altamaha River is formed in the southeastern portion of the State by the junction of the Ocmulgee and Oconee rivers. It is a navigable stream 70 miles long. As this service has no gauge on the Altamaha, it is impossible to estimate the effects upon it of freshets in its confluent. The course of the Altamaha is southeastward through a very flat section of the State.

The Ocmulgee River rises in north central Georgia, about 50 miles northeast of the source of the Flint River. The only gauge the service has on this stream is at Macon, a place about half the distance between its source and junction with the Oconee. Rains about its headwaters affect the gauge at Macon within twenty-four hours. The country through which this river flows is very flat, and except the country along the Coosa, at Rome, experiences the most damaging floods in the State. The rises at Macon are unusually sudden, frequently doing much damage in that city. Last January there was a rise at Macon of 12 feet within less than sixteen hours. The falls are as rapid as the rises.

The Oconee River rises about 40 miles east of the source of the Ocmulgee and flows southerly, almost parallel with that stream, to the point of their junction. The only gauge on the Oconee is at Dublin, about 40 miles above its junction. Rains along its headwaters cause a rise at Dublin within twenty-four hours, the maximum effects of such rains, however, not occurring until four days after anything like general rains have ended. The danger line at Dublin is 17 feet on the gauge.

The danger lines, high-water marks, etc., as published in "Daily river stages at river gauge stations on the principal rivers of the United States for the years 1890-92, Part IV," remain unchanged.

The most dangerous periods on all the rivers in Georgia are during the spring and early summer, and the crops most damaged are corn and cotton. In the northern portion of the State floods frequently delay the planting of corn and other early crops.

CAIRO, ILL.

By W. T. BLYTHE, *Local Forecast Official.*

Approaching Evansville from the south, the Ohio River makes a sharp curve and runs southeast from that city about 4 miles, then curves southeasterly 4 miles, south 1 mile, southwest 5 miles, northwest 2 miles, north by east 4 miles to Cypress Bend, where a sharp curve is made to west by south. (From a point about 4 miles below Evansville to Cypress Bend, the air-line distance in a southwest direction is about 3 miles, while the distance by river is about 17 miles.) From Cypress Bend to Walnut Bend, 9 miles, or 3 miles below foot of Diamond Island, the course is west by south; from Walnut Bend to Mount Vernon, 5 miles, northwest; from Mount Vernon to Uniontown, Ky., about 13 miles, south by west; and from Uniontown to mouth of Wabash River, 6 miles, northwest; from the mouth of the Wabash River southwest, 13 miles; thence south by east to Tradewater Bar, 12 miles; there it curves southwest to Weston, Ky., 2 miles; from Weston, Ky., its course is almost due west to Elizabethtown, Ill., 13 miles; from Elizabethtown, southwest, 4 miles to Irish Jimmies Bar; thence northwest 3 miles to Grand Pier Bar; from Grand Pier Bar, southwest, 4 miles; thence south by west, 8 miles, to Sisters Island; thence south by east to the mouth of the Cumberland River at Smithland, about 11 miles; from Smithland, southwest, 6 miles; thence northwest passing Paducah, Ky., and Brooklyn, Ill., to head of Grand Chain, a distance of 30 miles; from the head of Grand Chain its direction is southwest, passing Caledonia, Ill., 8 miles, Mound City, Ill., 16 miles, to a point 4 miles below Mound City and 1 mile above Cairo, where it curves to the south and easterly, passing Cairo, and empties into the Mississippi 1 mile below Cairo, running southeast.

PRINCIPAL AFFLUENTS OF THE OHIO RIVER BELOW CINCINNATI, OHIO.

Kentucky River enters at Carrollton, Ky., about 60 miles above Louisville. Its north and south forks rise in the Cumberland Mountains and unite at Proctor, Ky. Its length, exclusive of branches, is estimated at 250 miles, or, including the North Fork, about 350 miles.

Green River, Kentucky, which is about 350 miles long, navigable for small steamboats for about 150 miles from its mouth, and drains the greater portion of central Kentucky, empties into the Ohio 8 miles above Evansville. (The greatest length of Green River is erroneously stated in Annual Report Chief Signal Officer, 1891, page 222, to be 175 miles.)

The rivers and principal creeks emptying into the Ohio River below Evansville are: Highland Creek, Kentucky, 48 miles below Evansville and 1 mile above Uniontown, Ky.

Wabash River, 54 miles below Evansville, 19 miles below Mount Vernon, Ind., and about 10 miles above Shawneetown, Ill. The Wabash River is about 550 miles long, is navigable to Vincennes, a distance of about 140 (?) miles from its mouth, and drains a large portion of eastern part of Illinois, three or four counties in northwestern Ohio, and nearly the whole State of Indiana.

Saline River, Illinois, 9 miles below Shawneetown, Ill., and 3 miles above Caseyville, Ky.

Tradewater River, Kentucky, 2 miles below Caseyville, Ky., and 2 miles above Weston, Ky. The Tradewater drains parts of Caldwell, Hopkins, Crittenden, and Union counties, Ky.

Big Cane Creek, Illinois, 2 miles below Weston, Ky., and 3 miles above Cave In Rock, Ill.

Big Creek, Illinois, 8½ miles below Cave In Rock, Ill., and one-half mile below Elizabethtown, Ill.

Big Bay Creek, Illinois, 20 miles below Elizabethtown, Ill., 8 miles below Golconda, Ill., and 1 mile above Bay City, Ill.

Cumberland River, Kentucky, at Smithland, Ky., 9 miles below Bay City, Ill., 2 miles above New Liberty, Ill., about 10½ miles above the mouth of the Tennessee River, and about 12 miles above Paducah, Ky. The Cumberland is one of the largest affluents of the Ohio River. It rises in Harlan County, Ky., and runs toward nearly every point of the compass except east. It intersects several counties in Kentucky and flows from Cumberland County southwestward to middle Tennessee, in which it runs nearly westward to Nashville. Below Nashville its general direction is north-westward, and reenters Kentucky from Stewart County. Its length is estimated at 650 miles. Steamboats ascend it to Nashville, 192 miles from its mouth, and it is navigable during high water for a considerable distance above Nashville.

Tennessee River, about 1½ miles above Paducah, Ky. The Tennessee River is formed by the Clinch and Holston rivers, which rise in Virginia and unite at Kingston, Roane County, Tenn. It flows southwestward to Chattanooga, where it turns abruptly to the right and runs nearly north about 40 miles, where a mountain range changes its course to the southwest again to Guntersville, Ala. Below this point it pursues a west-northwest direction until it touches the State of Mississippi. It next bends to the right, returns to the State of Tennessee, runs northward, enters Kentucky at the southeast corner of Trigg County and the Ohio River near Paducah. It is the largest affluent of the Ohio and is about 800 miles long, excluding branches. Large steamboats ascend the Tennessee to Hamburg, Tenn., 233 miles above its mouth, all the year, and to Florence, Ala., about 65 miles farther, except during very low water. Big Bend Shoals, Big Tree Shoals, and Colbert Shoals, between Hamburg, Tenn., and Florence, Ala., make navigation unsafe and at times impracticable during low-water periods. Above and near Florence navigation is obstructed by rocky rapids called Muscle Shoals. Above Muscle Shoals the river is again navigable for steamboats to Kingston, Tenn. It has an affluent called the Little Tennessee, about 150 miles long,

which rises near the north border of Georgia and runs northward through Macon County, N. C., turns westward, passes into Tennessee, and enters the Holston River about 7 miles above Loudon, Tenn. Another affluent is Clarks River, Kentucky, about 75 miles long; empties into the Tennessee about 1 mile above its mouth.

Island Creek, Kentucky, enters the Ohio River one-half mile above Paducah.

Perkins Creek, Kentucky, 5 miles below Paducah and 2 miles below Brooklyn, Ill. Seven Mile Creek, Illinois, at Belgrade, Ill., 6 miles below Paducah and 3 miles below Brooklyn, Ill.

Massac Creek, Illinois, $1\frac{1}{4}$ miles below Belgrade, Ill., and 2 miles above Metropolis, Ill.

Massac Creek, Kentucky, $1\frac{1}{4}$ miles below Metropolis, Ill.

Little Run Creek, Kentucky, 3 miles below Metropolis, Ill., and 2 miles above Little Chain.

Hunting or Redstone Creek, Kentucky, 19 miles below Paducah and 4 miles above Head of Grand Chain.

Humphries Creek, Kentucky, 10 miles below head of Grand Chain, 8 miles below Grand Chain Landing, Ill., 5 miles below foot of Grand Chain, 2 miles below Caledonia, Ill., and 6 miles above Mound City, Ill.

Cache River, Illinois, 1 mile below Mound City, Ill., and about 4 miles above Cairo, Ill. The Cache is about 70 miles long and drains part of Johnson, Pulaski, and Alexandria counties, Ill.

ISLANDS, BARS, AND OTHER OBSTRUCTIONS IN THE OHIO RIVER BETWEEN EVANSVILLE, IND., AND CAIRO, ILL.

Henderson Towhead, head 7 miles and foot 9 miles below Evansville and 1 mile above Henderson, Ky.

Henderson Island, head 1 mile and foot 2 miles below Henderson, Ky.

Diamond Island, head near West Franklin, Ind., 13 miles below Henderson, Ky., foot 3 miles below West Franklin and 8 miles above Mount Vernon, Ind.

Slim Island, head 3 miles and foot 7 miles below Mount Vernon, Ind.

Mississippi Bar, head 9 miles and foot 11 miles below Mount Vernon, Ind.

Upper Highland Rocks (right bank), 12 miles below Mount Vernon and 1 mile above Uniontown, Ky.

Lower Highland Rocks (left bank), 2 miles below Uniontown, Ky.

Wabash Island, opposite mouth of the Wabash River, the head 4 miles and foot 8 miles below Uniontown, Ky., and 8 miles above Shawneetown, Ill.

Browns Island, 3 miles above Shawneetown, Ill.

Cincinnati Towhead, 6 miles below Shawneetown, Ill.

Saline Bar and Saline Towhead, opposite and above mouth of Saline River, 8 miles below Shawneetown.

Blakeleys Bar and Blakeleys Towhead, 11 to 12 miles below Shawneetown and 1 mile above Caseyville, Ky.

Caseyville Bar, opposite Caseyville, Ky.

Tradewater Bar, opposite mouth of Tradewater River, and 1 to 2 miles below Caseyville, Ky.

Towhead, one-half mile below mouth of Tradewater River.

Cave in Rock Island, head $6\frac{1}{2}$ miles and foot $7\frac{1}{2}$ miles below Caseyville, and one-half mile above Cave in Rock, Ill.

Walkers Bar, 3 miles below Cave in Rock, Ill.

Half-Moon Bar, 3 to 5 miles below Cave in Rock, Ill.

Hurricane Island Towhead, $4\frac{1}{2}$ miles below Cave in Rock, Ill.

Hurricane Island, head $4\frac{1}{2}$ miles and foot opposite Elizabethtown, Ill., 8 miles below Cave in Rock.

Irish Jimmies Bar, 4 to 5 miles below Elizabethtown, Ill.

Grand Pier Bar, opposite mouth of Grand Pier Creek, 8 miles below Elizabethtown, Ill.

Randolph Island, 3 to 4 miles below mouth of Grand Pier Creek and foot 1 mile above Golconda, Ill.

Pryors Island, head $2\frac{1}{2}$ miles and foot 4 miles below Golconda.

Loose Rocks (near right bank), $2\frac{1}{2}$ to 3 miles below Golconda, Ill.

Sisters Island, head 6 miles and foot 7 miles below Golconda, Ill., and 2 miles above Bay City, Ill.

Stewarts Island, head 2 miles below Bay City, Ill., and foot opposite Birds Point Landing, Ky., $3\frac{1}{4}$ miles below Bay City.

Dog Island, 4 to 5 miles below Birds Point Landing and 1 mile above the mouth of the Cumberland River, at Smithland, Ky., which is opposite Hamlettsburg, Ill.

Cumberland Island extends from one-half mile above mouth of Cumberland River to near New Liberty, Ill., 2 miles below.

Hamlettsburg Bar lies opposite the village of Hamlettsburg and between it and Cumberland Island.

Towhead, opposite New Liberty, Ill., 2 miles below mouth of Cumberland River.

Cottonwood Bar, opposite mouth of Caney Creek, Kentucky, 4 to 5 miles below Smithland, Ky., and 7 to 8 miles above Paducah, Ky.

Indiana Bar, $4\frac{1}{2}$ miles above Paducah, Ky.

Tennessee Island, about 1 mile long, from opposite mouth of Tennessee to opposite Paducah.

Sand Bar, about 1 mile long, opposite Paducah, Ky.

Belgrade or Fort Massac Bar, opposite the village of Belgrade, Ill., 6 miles below Paducah, Ky., and 2 miles above Metropolis, Ill.

Little Chain (rocks), 4 to 5 miles below Metropolis, Ill.

Grand Chain (of rocks) extends from "head," near Wilkinsons Landing, 13 miles below Metropolis, to "foot," near Barbers Landing, $2\frac{1}{4}$ miles above Caledonia, Ill., or a distance of about 6 miles.

Wreck of *Northerner* and wreck of *Suwanee*, at foot of Grand Chain, one-fourth to one-half mile above Barbers Landing, Ill.

Cache Island, near left bank and Mound City Towhead near right bank, from $5\frac{1}{2}$ to 7 miles below Caledonia, Ill., and from $1\frac{1}{2}$ above to opposite Mound City, Ill.

Weston Rock, at the mouth of the Ohio River, about 1 mile below Cairo.

Two railroad bridges cross the Ohio below Evansville, viz, that of the Louisville and Nashville at Henderson, Ky., and of the Illinois Central, 1 mile above Cairo.

LANDS SUBJECT TO OVERFLOW AT CERTAIN STAGES, MEASURED ON THE WEATHER BUREAU GAUGES MAINTAINED AT EVANSVILLE, MOUNT VERNON, MOUNT CARMEL, PADUCAH, AND CAIRO.

At 30 feet on the Evansville gauge, the water begins to leave the river banks and spread over the lowlands on both sides of the river. At 36 feet a current sets in from a point about 4 miles below Evansville to Cypress Bend, about $3\frac{1}{4}$ miles distant, in a southwest direction, where it reenters the river 17 miles below by the main channel. At 40 feet all the low farming lands, embracing large areas on both sides of the river above and below Evansville, are said to be submerged.

Mount Vernon, Ind., is 36 miles, by river, below Evansville. It is above the highest stages on record. But in its immediate vicinity, on both sides of the river both above and below, there are large areas of improved and highly productive farming land, which are subject to overflow at 28 feet and upward on the Mount Vernon gauge, provided the stage at Mount Carmel, Ill., on the Wabash River, is at the same time 15 feet or more.

Stages of from 33 to 37 feet at Cincinnati, dependent upon the amount of water coming out of the Kentucky, Green, and Wabash rivers, give 28 feet and upward on the Mount Vernon gauge three to four days after the above readings are observed at Cincinnati, and 40 feet at Cincinnati with a simultaneous stage of 15 feet or upward

at Mount Carmel, it is said by old residents of Mount Vernon, floods the lowlands between West Franklin, 12 miles above, and Mount Vernon, also a large area in Henderson County, Ky., opposite Mount Vernon, and nearly the whole of Point Township, Posey County, Ind., containing 32,000 acres, rated with the best producing land in the State, and which lies in the crotch between the Ohio and Wabash rivers.

In addition to the above, there are also extensive tracts of improved land on both sides of the Wabash River from its mouth to above Mount Carmel, Ill., which are inundated at stages of 15 feet at Mount Carmel and 28 feet at Mount Vernon.

From Shawneetown to Paducah no specific, reliable information has as yet been obtained as to districts subject to overflow, but it is believed that the areas are small and that the damage likely to ensue is also comparatively small.

At 37 feet on the Cairo gauge the river begins to leave its banks about 20 miles below Paducah and runs across the lowlands to Fort Jefferson, Ky., about 6 miles below Cairo on the Mississippi River. At 40 feet on the Cairo gauge the entire country, except the Illinois Central Railroad and Mobile and Ohio Railroad embankments, east of the river and west of a line drawn from 20 miles below Paducah to Fort Jefferson is covered with water. At 40 feet on the Cairo gauge the Mississippi is also running over its banks at Birds Point, Mo., and with higher stages the water rapidly spreads over hundreds of square miles in Mississippi, Scott, Stoddard, and other counties south of them in Missouri.

CINCINNATI, OHIO.

By Mr. S. S. BASSLER, *Local Forecast Official.*

It is well known that a good rise out of the Alleghany will give river men fully double the time that an equal rise out of the Monongahela does.

The upper Ohio being a known quantity, the Kanawha is watched more closely than when its surprises are expected. Streams flowing into the Ohio from the north do not affect it as quickly as those flowing into it from the south.

* The Muskingum is a sluggish stream as compared with the southern tributaries.

Although the Scioto sometimes brings a great deal of water, it is also a sluggish stream and little attention is paid to it.

The Kanawha of all the southern tributaries carries the most water, and is considered the most important factor in Ohio River rises.

Touching the estimates made as to the stage of water in consequence of a certain stage at any point above, it is believed that such estimates are simply guesswork. There is seldom any agreement on the probable stage.

CHARLESTON, S. C.

By L. N. JESUNOFSEY, *Local Forecast Official.*

The South Carolina river service, as at present organized, comprises nine stations, as follows: Camden, S. C., on the Wateree River; Cheraw, S. C., on the Great Pedee River; Columbia, S. C., on the Congaree River; Conway, S. C., on the Waccamaw River; Edisto, Barnwell County, S. C., on the Edisto River; Effingham, S. C., on the Lynch River; Fairbluff, N. C., on the Lumber River; Kingstree, S. C., on the Black River; St. Stephens, S. C., on the Santee River.

Observations on the stages of water, the state of weather, wind directions, and measurements of precipitation are made daily at 8 a. m. during the flood seasons—January to March, inclusive, and July to October, inclusive—and sent by mail upon a printed card provided for the purpose.

When rainfall of 1 inch or more occurs, and the rivers have risen 6 feet or more during the preceding twenty-four hours, the observations are then sent by telegraph to the Charleston, S. C., center. At the end of the month the daily observations are

tabulated upon a form and sent to the section center, where they are verified, and then transmitted to the chief of the Weather Bureau. The daily river reports are embodied in a table which appears regularly upon the daily weather chart issued from this station. The data from this table is then transcribed upon small blanks for publication in the *Daily News and Courier of Charleston, S. C.*

When floods are imminent telegrams and postal cards are forwarded to 43 towns along the streams mostly affected.

All streams over the coast region of this State east and south of lines drawn from Barnwell, Barnwell County, to Vance, Orangeburg County, to Camden, Kershaw County, and thence over to Cheraw, Chesterfield County, are subject to overflow, causing much inconvenience to traffic, loss of live stock, and injury to crops. West and north of this boundary the contour changes to a decided elevation, and freshets are less frequent than over the coast region.

With imperfect data as to the width and drainage area, the method of forecasting floods in South Carolina is, as yet, somewhat crude. We know approximately the area of the Santee, Pedee, and Waccamaw River basins. Very good results have, however, followed the systematic study of rainfall measurements with regard to the volume of water in the upper streams and the rate of increase in the lower streams.

Each stream will be treated upon separately in this paper, as no single rule, except as to variable rainfall measurements, applies to all.

THE WACCAMAW RIVER BASIN.

Length of the Waccamaw River above Conway, S. C., 151 miles; length of the Waccamaw River below Conway, S. C., 63 miles; drainage area above Conway, S. C., 1,140 square miles; drainage area below Conway, S. C., 432 square miles. The drainage area is combined with that of the Great Pedee basin for 20 miles above Winyah Bay. It extends for about 5 miles westward along the stream above the junction of the Waccamaw and Great Pedee rivers, and continues for 5 miles west of the stream, until it reaches the State line; the area then narrows down considerably, until within a short distance of Lake Waccamaw, in North Carolina, near the head waters of the Waccamaw River. The eastern limit of the Waccamaw basin embraces nearly all of that territory adjoining the Atlantic, curving westward toward the river at Nixonville, S. C., for about 3 miles. The line follows the eastern limits of the Caw Caw, the Green, and Big swamps, in North Carolina; thence northward, close to the Cape Fear River drainage area, and westward to Rosendale, Columbus County, N. C., where it terminates.

The gauge station within the Waccamaw basin is located at Conway, S. C. The gauge was formerly used by the United States Engineer Corps. It was repaired by the United States engineer and placed at the disposal of the Weather Bureau in November, 1893. Length of gauge, 10 feet; width, 0.6 foot; thickness, 0.1 foot. Gauge painted white; graduations in feet and tenths, and painted black. Position of gauge, Conway Toll Bridge pier; elevation of zero of river gauge above sea level, 25 feet; width of river at Conway, 285 feet; flood or danger line, 7 feet; river overflows at 8 feet; territory overflowed at this gauge reading, 5 miles; highest water known, equal to reading on gauge, 9 feet, February 9, 1895; lowest water known, equal to reading on gauge, 0.0 feet, August 16, 1889. Owing to its low elevation and the small rate of descent, the Waccamaw at Conway rarely rises over 1 foot in twenty-four hours. It may have an almost uniform rise of 4 inches per day for about five days, and then begins to recede slowly, unless checked in its downward tendency by additional heavy rainfall, in which case the rate of increase is exceedingly small. During heavy rainfalls at Conway, S. C., the rise in the stream seldom exceeds 6 inches per day for one day or more than two days. This is due to the fact that the water spreads over a larger territory, not being confined within the river's banks.

With a rainfall of 2 inches reported from Fairbluff, N. C., near the western edge of the upper Waccamaw basin, the wave crests usually reach Conway, S. C., in

three and a half days. The rising waters require an additional period of two and a half days before reaching Winyah Bay.

The Waccamaw River is navigable for 7-foot draft boats to Conway. Beyond Conway the depth is less, though steamers drawing 3 to 4 feet run to a point 40 miles above that town at possibly the lowest stages of water. The river has its chief source in Waccamaw Lake, North Carolina, and after flowing in a southwesterly direction, approximately parallel to and not far from the seacoast, empties into Winyah Bay, at Georgetown, S. C. The lake is a body of fresh water about 3 miles wide and 5 miles long, with a probable average depth of 8 feet, situated on the line of the Wilmington, Columbia and Augusta Railroad, about 25 miles west of Wilmington, N. C. The total length of the river is about 214 miles, and the distance from head to mouth, by a straight line, would probably be 80 miles. There is very little current on the lower Waccamaw, but a much greater velocity is found in the upper portion.

The river reports from Conway, S. C., are principally used by steamboat men, stock breeders, lumbermen, and rice planters.

THE PEDEE BASIN.

There are four drainage areas within the Great Pedee basin, namely, the Little Pedee, the Great Pedee, the Lynch, and the Black.

LITTLE PEDEE BASIN.

The Little Pedee basin runs almost parallel with the river on both sides, its width averaging about 5 miles. It empties into the Great Pedee at Port Harrelson. The Lumber River, in North Carolina, is a continuation of the Little Pedee.

The gauge station within the Little Pedee basin is located at Fairbluff, N. C., on the Lumber River. Length of the Little Pedee River above Fairbluff, N. C., 102 miles; length of the Little Pedee River below Fairbluff, N. C., 86 miles; drainage area above Fairbluff, N. C., 410 square miles; drainage area below Fairbluff, N. C., 330 square miles.

The river gauge was erected in December, 1893, and is the property of the Weather Bureau. Length of gauge, 9 feet; width, 0.8 foot; thickness, 0.1 foot. Gauge is painted white; graduations painted black, in tenths of feet, the whole feet being represented by brass figures.

Position of gauge: On west side, central pier, of Fairbluff (N. C.) free bridge; Elevation of zero of river gauge above sea level, 59 feet; width of river at Fairbluff, N. C., 270 feet; flood or danger line, 6.5 feet; river overflows at 7 feet; territory overflowed at this gauge reading, 2 miles; highest water known, equal to reading on gauge, 9 feet, March, 1848; lowest water known, equal to reading on gauge, 0.0 feet, June 1, 1893.

The rise of water in this stream at any gauge reading does not exceed $1\frac{1}{2}$ feet in twenty-four hours. With a rainfall of about 1 inch reported from Cheraw, S. C., near the head waters of the Little Pedee, or Lumber River, at a moderate stage, this stream will rise 3 to 4 inches per day for about five days. If the rainfall continues over the upper portion of this basin for a few days, and increases 1 inch or more for each day, the rate of rise in the stream is much greater, although the depth of water does not increase to a much greater extent, as it spreads over a much larger area, oftentimes for 3 miles on each side of the river.

It requires three days for the wave crests to reach Fairbluff, N. C., from the head waters. Within another three days' interval the advancing volume of water merges with the Great Pedee a few miles above Port Harrelson, S. C.

This stream is navigable for 3-foot draft vessels from Port Harrelson, S. C., to Fairbluff, N. C., at an ordinary stage of water.

Stock breeders, raftsmen, lumbermen, and steamboat men are greatly interested in the gauge readings reported from Fairbluff, N. C.

THE GREAT PEDEE BASIN.

The Great Pedee, emptying into Winyah Bay, Georgetown, S. C., has, including its upper portion, called the Yadkin, a total length of about 465 miles and a combined drainage area of 16,329 square miles, including the drainage area of its main tributaries, the Little Pedee, the Lynch, and the Black rivers. At a stage of about 0.5 foot above low water the discharge at Cheraw is about 7,000 cubic feet per second.

The stream is navigable for boats of 9 feet draft from Winyah Bay to Smith's Mills, 78 miles; thence navigable for boats of 3.5 feet draft to Cheraw, S. C., for 93 miles.

The river changes its name from that of Great Pedee to that of the Yadkin at the entrance of the Uharie, or Narrows, in North Carolina, 71 miles above Cheraw, S. C. This river, above the Narrows, is about 200 miles long, with a drainage area of about 4,320 square miles, and nearly 600 feet wide; dropping to 40 to 50 in its 2-mile passage through the Narrows, and expanding again to about 500 feet in width at the lower end of the Narrows, with an outflow of 2,500 cubic feet of waterpower per second at low water, and rising to 12 feet in height during freshets. From the Narrows it flows in a general southerly direction for 71 miles before it reaches Cheraw, the present head of steam navigation. From Cheraw to the Narrows the elevation increases rapidly. From the State line, 13 miles up, to the Carolina Central Railroad the river surface has a rise of 37 feet, and a tolerably uniform slope of 2.8 feet to the mile. From the Carolina Central Railroad, 51 miles up, to the Narrows the river surface has a rise of about 310 feet, and a tolerably uniform slope of over 5.5 in addition to two special rapids (Bluetts Falls and Grassy Island Shoals) of 4 miles total length, and 10 feet rise per mile. A slope of 5.5 per mile is much greater than can be safely ascended by shallow-draft boats.

The Great Pedee runs in a southeasterly direction from Cheraw, S. C., to Port Harrelson, S. C., near the mouth of the Little Pedee. The lower section of this stream runs almost in a southerly direction from Port Harrelson to Winyah Bay. From Cheraw, S. C., to Georgetown, S. C., at the head of Winyah Bay, the river has an average slope of one-half foot to the mile.

The gauge station on the Great Pedee is located at Cheraw, S. C. Length of the Great Pedee above Cheraw, S. C., 294 miles; length of the Great Pedee below Cheraw, S. C., 171 miles; drainage area of the Great Pedee above Cheraw, S. C., 9,045 square miles; drainage area of the Great Pedee below Cheraw, S. C. including the Little Pedee, the Lynch, and the Black systems, 7,284 square miles.

The river gauge was erected in 1887 by the United States Engineer Corps, and placed in possession of the Weather Bureau in May, 1891. Length of gauge, 38 feet; width, 1 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in feet and tenths. Position of gauge: on Cheraw toll bridge, east central pier. Elevation of zero of river gauge above sea level, 50 feet. Width of river at Cheraw, S. C., 450 feet; flood or danger line, 27 feet; river overflows, at this gauge reading, on west side at 26 feet; on east side at 31.6 feet. Territory overflowed at these gauge readings: At Cheraw, S. C., for one-half mile above and for 10 miles below Cheraw. Highest water known, equal to reading on the gauge, 37.3 feet, March 11, 1875; lowest water known, equal to reading on the gauge, 0.0 feet, August, 1866.

There is no stream in the State which rises more uniformly, with certain rainfall supply, than the Great Pedee at and above Cheraw, S. C. The precipitation measurements of Charlotte, N. C., are true indexes of what may be expected in the way of height of wave crests when reaching Cheraw. A 1-inch rainfall reported from Charlotte, N. C., most invariably causes the stream at Cheraw to rise 8 to 12 feet, and a 2-inch rainfall 12 to 22 feet. Quite satisfactory rain forecasts for the Great Pedee were made upon this basis. Observations from the special rainfall station at Salisbury, N. C., on the upper Great Pedee, made during 1893 and 1894, would seem to bear out these facts.

We are told by the United States Engineer Corps, which made surveys of this stream in 1876, 1879, and 1888, particularly between Cheraw, S. C., and the Narrows in North Carolina, close to the Uharie River, with a view to developing its immense water powers, that there are three large and natural waterfalls, over 40 feet in height, within a range of 21 miles, and that the slope for a distance of 71 miles above Cheraw is 355 feet, or an average of 50 feet to the mile. At the Narrows, on the Yadkin (which is an extension only of the Great Pedee), the amount of fall is 40 feet in 2 miles. At Grassy Island Rapids, 281 miles from and 180 feet above the Atlantic, the fall is 30 feet in 3 miles. At Blunett Falls, 279 miles from and 150 feet above the Atlantic, the fall is 12 feet in 1 mile. From this data it will be seen that the water descends with terrific force seaward, from the Narrows toward Cheraw, S. C. The stream at Cheraw has been known to rise 26.5 feet in sixteen hours. It frequently rises 20 feet or more in twenty-four hours, and has been known to decline 18 to 22 feet within the same time.

The wave crests on the upper Great Pedee reach Cheraw, S. C., in three days from the commencement of the rise to the time of falling. Below Cheraw conditions are somewhat different. It requires eight and a half days for the water to reach Georgetown, S. C., at the head of Winyah Bay, from Cheraw, S. C., where the drainage arises from the Great Pedee alone. When precipitation occurs over the entire basin of the Great Pedee, the waters of the Little Pedee, the Lynch, and the Black unite slowly with the Great Pedee and produce considerable of a freshet at the head of Winyah Bay.

Occasionally a second rise in the Great Pedee at and above Cheraw, S. C., following close after the first, may overtake the first rise on its oceanward voyage, and cause the stream near Georgetown, S. C., to remain at a higher stage for a greater period than is ordinary. During the rice-growing season, when the freshets meet the maximum tides, much rice is injured thereby.

Two-thirds of the timber cut upon the Great Pedee and its tributaries is sent in rafts to Georgetown, S. C., where it is carried to the mills. The river reports above Georgetown form an important item in the lumberman's business. Without them they could not prepare their logs in time for rafting out of the swamps. The reports also enable stockmen to protect their cattle from sudden rises. Steamboat men regulate the size of their cargoes by the information contained in the river observations from Cheraw, S. C., and other stations along the tributaries of the Great Pedee. The downward freights are cotton, spirits of turpentine, rosin, tar, rice, timber, cypress lumber, and shingles. The upward freights are fertilizers and general merchandise.

THE LYNCH RIVER BASIN.

The Lynch River is the smallest of the three tributaries belonging to the Great Pedee. It empties into the Great Pedee 30 miles below Effingham, S. C., and runs in a southeasterly course from its headwaters at the State line to its confluence with the Great Pedee. Its rate of slope is relatively small, being about 6 inches to the mile from the State line to Tillers Ferry, S. C., and averaging 4 inches to the mile from Tillers Ferry, to Effingham, S. C., and below.

On account of its elevation the stream rises much faster at Tillers Ferry, S. C., than at Effingham, S. C. During heavy rainfalls the greatest rate of increase is 3 feet per day at Tillers Ferry, while at Effingham, S. C., it seldom rises 1.4 feet in any twenty-four hours.

The effect of rainfall at Cheraw, S. C., and Camden, S. C., bears a wonderful influence upon the drainage system of the Lynch River. One-inch rainfalls at Camden, S. C., may produce a rise of 2 to 4 feet in about three days at Effingham, S. C. As a rule the water recedes very slowly at and below Effingham, S. C., due doubtless to its close proximity to the waters of the Great Pedee, which serves as a check to its downward progress.

The gauge station within the Lynch basin is located at Effingham, S. C.

Length of the Lynch River above Effingham, S. C., 75 miles; length of the Lynch River below Effingham, S. C., 30 miles; drainage area of the Lynch River above Effingham, S. C., 335 square miles; drainage area of the Lynch River below Effingham, S. C., 110 square miles.

The river gauge was erected in May, 1891, and is the property of the Weather Bureau. Length of gauge, 20 feet; width, 0.4 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in feet and tenths. Position of gauge, 6 feet on upright support; extension of 14 feet on large tree. Elevation of zero of river gauge above sea level, 65 feet; width of river at Effingham, S. C., 120 feet; flood or danger line, 12 feet; river overflows at 12 feet; territory overflowed at these gauge readings, one-half mile. Highest water known, equal to reading on the gauge, 17.5 feet, January 24, 1892; lowest water known, equal to reading on gauge, 0.0 foot, 1884.

The stream is navigable for 3-foot draft boats from its mouth at the Great Pedee to Effingham, S. C.

The principal industry on the Lynch River is log rafting, which begins in September and ends in April. The river reports from Effingham are also used extensively by the rice and cotton planters on the Great Pedee, near the mouth of the Lynch River.

THE BLACK RIVER BASIN.

This stream is one of the tributaries of the Great Pedee. Navigation is uninterrupted for light-draft steamers between the mouth of the Great Pedee and Kingstree, S. C., on the Northeastern Railroad, except during the low-water season in the summer months, when but few steamers ply up this stream. Much lumber is rafted upon the upper Black River. On the lower Black River rice, cotton, and naval stores are shipped in large quantities, and stock breeders suffer greatly during freshets.

The rainfall at Camden, S. C., affects the gauge readings at Kingstree, S. C. A 1-inch rainfall at that place will cause a rise of about $1\frac{1}{4}$ feet at Kingstree. A 2-inch rainfall at Kingstree elevates the stream but a few inches there. The greatest danger from overflow occurs some 45 miles below Kingstree, near the mouth of the Black, where the river is much wider than above stream. The backing tide water from Wingate Bay, the freshets from the Great Pedee, together with the rising waters from the Black and Waccamaw, form a continuous sheet of water for many miles, and oftentimes cause great loss to crops and other products. This danger has been avoided to a large extent since the river service of the Bureau has been in operation.

There is one river-gauge station within the Black River basin, located at Kingstree, S. C. Length of the Black River above Kingstree, 64 miles; below Kingstree, 52 miles. Drainage area of the Black River above Kingstree, 301 square miles; below Kingstree, 168 square miles.

The river gauge was erected in December, 1893; it is the property of the Bureau. Length of gauge, 15 feet; width, 0.8 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in tenths of feet, the whole feet being represented by brass figures. Position of gauge, on middle south pier of Kingstree free bridge. Elevation of zero of gauge above sea level, 37 feet; width of river at Kingstree, S. C., 250 feet; flood or danger line, 12 feet; river overflows at 14 feet; territory overflowed at three gauge readings, 3 miles west and south of Kingstree. Highest water known, equal to reading on the gauge, 14.5 feet, September, 1893; lowest water known, equal to reading on the gauge, 0.0 foot, May, 1888.

THE SANTEE RIVER BASIN.

The Santee River, formed by the Congaree and Wateree rivers, has, from the sea to its headwaters in the mountains, a total length of about 500 miles, and a drainage

area of about 15,414 square miles. The river is connected by canal, to Winyah Bay, through a portion of Mosquito Creek.

The Congaree River, formed by the Broad and Saluda rivers, and itself uniting with the Wateree to form the Santee, has, from the headwaters of its tributaries in the mountains to its mouth in the Santee, a total length of about 250 miles, and a total drainage area of about 8,312 square miles. The name Congaree applies therefore to 50 miles of river from the confluence of the Broad and Saluda, just above Columbia, S. C., downward to the Santee, at Wateree, S. C.

The Catawba is a river of about 207 miles length, and 4,280 square miles of drainage area. It rises in the Blue Ridge Mountains, McDowell County, N. C., near the Western North Carolina Railroad, close to the main divide between the Atlantic and Mississippi basins. It runs first easterly, then southerly through portions of North and South Carolina, and takes the name Wateree at the junction of Wateree Creek, a small tributary entering from the west in the upper part of Fairfield County, S. C., above Camden, S. C.

The Wateree is a continuation of the Catawba, from Camden, S. C., to Wateree, S. C., and unites with the Congaree to form the Santee.

The Santee continues in a southeasterly direction for a distance of 184 miles, and empties into the Atlantic 14 miles south of Winyah Bay. A State canal connects with the Santee at Ferguson, S. C., and runs into the headwaters of the Cooper River at Monks Corner, S. C., thus affording navigation inland from the Santee River to the Charleston (S. C.) Bay.

The surface of the Catawba River from the State line to Camden, S. C., has a descent of 325 feet in 75 miles, or an average of 4.5 feet per mile. At Great Falls, Catawba Canal to Rocky Mount, the amount of descent is 178 feet in 8 miles, of which 50 feet covers one-fourth of a mile. At the Wateree Canal Shoals, slightly above Camden, the descent is 52 feet in 5 miles. The slope ranges from 175 feet above sea at Camden, S. C., to 7.4 feet above sea at Wateree, S. C., where the Congaree and Wateree rivers empty into the Santee; from Wateree, S. C., to St. Stephens, S. C., the surface slope decreases gradually to 50 feet above sea.

It will thus be seen, judging from the rate of descent, that the Catawba, from its headwaters to Camden, S. C., flows very rapidly, most notably during high water. A portion of the water supply registered in the vicinity of Charlotte, N. C., also feeds the Catawba, through one of its small tributaries. According to rainfall measurements on the Catawba, made at Mount Holly, N. C., near the State line, this stream rises, approximately, 8 to 14 feet at Camden, S. C., for each inch of rainfall recorded at Mount Holly, N. C. The volume of water is considerably augmented by rainfall measurements of 1 inch or more at Camden, S. C.

The rising waters from the upper Catawba reach Camden in two and a half days. Two days usually elapse before the stream begins to recede at this point. The flood waters travel much slower between Camden on the Wateree and St. Stephens on the Santee, and reach the latter place in about four and a half days. Two days more are required for the greatly decreased and advancing wave-crests to reach the sea. As in the case of the Great Pedee, a second rise in the Catawba occasionally overtakes the preceding rise before passing half way through the Santee.

The Catawba at Camden has been known to rise 20 feet in one day; it frequently rises 6 feet in twenty-four hours, and continues at this rate for two and even three days. The rates of increasing or decreasing waters in the Catawba are not so great as those observed on the upper Great Pedee.

The immense width and low elevation of the Santee accounts for the slow progress of its waters seaward. The river overflows at a comparatively low stage, and the water spreads over many miles of territory. Rainfalls at any of the river stations above the Santee must be exceptionally heavy to elevate the stream 1 foot in twenty-four hours at St. Stephens. It rises 1 to 2 inches per day for one week or more, remains stationary for one or two days, and then recedes slowly.

During periods of high water the Congaree, at Columbia, S. C., rises about 8 feet in twenty-four hours. It seldom rises over 15 feet in any one day. It remains at a tolerably low stage the entire year.

The ascent of the Congaree to Columbia, S. C., is very steep, from 74 feet above sea at Wateree, S. C., to 235 feet above sea at Columbia, S. C. In its descent from Columbia, S. C., the water passes over three natural dams at Granby, 2 miles below Columbia. The Congaree is navigable from Wateree to Granby. Between Columbia and Granby the slope of the natural water surface at low stage is made up of a succession of pools and rapids. The total fall from Gervais street bridge to Granby, the present head of navigation, varies with the stage of water as follows: At 1 foot above low water, Gervais street gauge, the fall of water surface in the 2 miles discussed is 8 feet; average slope per mile, 4 feet; maximum slope per mile, 12 feet. At 5 feet above low water on the Gervais street gauge the fall of water surface in the 2 miles discussed is 4 feet; average slope per mile, 2 feet; maximum slope per mile, 2 feet. The rising waters reach Columbia, S. C., from the upper Broad River in two and a half days; in one and a half days this advancing volume meets the Santee River at Wateree. Wave-crests first observed at Coronaca, S. C., on the Saluda, reach the Congaree at Columbia in about one day and a half.

Measurements of rainfall made at Gaffney City, S. C., on the upper Broad River during 1893 and 1894 showed a close relation between the water supply over that locality and the amount which passed by Columbia. Rainfall measurements also made at Greenville, S. C., and Coronaca, S. C., for the same period, on the upper Saluda substantiate these facts.

There are three river-gauge stations within the Santee-Catawba-Congaree River basin, namely: (1) At St. Stephens, S. C., on the Santee; (2) at Camden, S. C., on the Catawba-Wateree; and (3) at Columbia, S. C., on the Congaree-Broad-Saluda.

1. The river gauge is located at St. Stephens, S. C., in the Santee basin. Length of the Santee River from St. Stephens, S. C., to Wateree, S. C., 75 miles; length of the Santee River below St. Stephens, S. C., 97 miles; drainage area of the Santee above St. Stephens, S. C., 12,614 square miles; drainage area of the Santee below St. Stephens, S. C., 2,800 square miles. The river gauge was erected in June, 1888, by the United States Engineer Corps, and was placed in possession of the Weather Bureau in April, 1892. Length of gauge, 20 feet; width, 0.5 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in feet and tenths, the whole feet being represented by brass figures. Position of gauge: On central stone pier of north-eastern railroad bridge. Elevation of zero of gauge above sea level, 420 feet; width of river at St. Stephens, S. C., 425 feet; flood or danger line, 20 feet; river overflows at 10 feet; territory overflows at this gauge reading for 3 miles on each side, both north and south, and for 6 miles below and above St. Stephens. Highest water known, equal to reading on the gauge, 20.2 feet, September 18, 1888; lowest water known, equal to zero reading on the gauge, July 18, 19, 1893.

2. The river-gauge station in the Catawba Basin is located at Camden, S. C. Length of the Catawba River above Camden, 230 miles; length of the Catawba-Wateree below Camden, 270 miles; drainage area of the Catawba above Camden, 7,892 square miles; drainage area of the Catawba-Wateree below Camden, 7,522 square miles. The river gauge was constructed by the United States Engineer Corps in 1888, abandoned in 1890, and placed in the possession of the Weather Bureau in May, 1891. Length of gauge, 36 feet; width, 0.8 foot; thickness, 0.1 foot, fastened to circular iron bridge pier. Gauge painted white; graduations painted black in feet and tenths, the whole feet being represented by brass figures. Position of gauge, on middle railroad bridge pier. Elevation of zero of gauge above sea level, 175 feet; width of river at Camden, S. C., 315 feet; flood or danger line, 24 feet; river overflows at 24 feet; territory overflowed at these gauge readings, 1 mile each on both sides. Highest water known, equal to reading on the gauge, 31.5 feet, September, 1886.

3. The river-gauge station in the Congaree Basin is located at Columbia, S. C.

Length of the Congaree River and its tributaries above Columbia, S. C., 210 miles; length of the Congaree River below Columbia, S. C., to Wateree, S. C., 40 miles; drainage area of the Congaree River and its tributaries above Columbia, S. C., 7,987 square miles; drainage area of the Congaree from Columbia, S. C., to Wateree, S. C., 325 square miles. The river gauge was constructed or painted by the United States Engineer Corps in 1887, abandoned in 1890, and placed in possession of the Weather Bureau in May, 1891. Length of gauge, 26 feet; width, 0.6 foot, painted on edge of stone pier; thickness of gauge, 4.5 feet, stone pier. Graduations painted black in feet and tenths. Position of gauge, on the northeast corner of central pier Congaree Toll Bridge. Elevation of zero of river gauge above sea level, 233 feet; width of river at Columbia, S. C., 3,200 feet; flood or danger line, 15 feet; river overflows at 14 feet; territory overflowed at this gauge reading, 1 mile below Columbia, S. C. Highest water known at these gauge readings, 24 feet, September, 1888; lowest water known at the gauge readings, 0.4 foot, June 20, 1893.

Navigation at Granby, S. C., on the Congaree River 2 miles below Columbia, S. C., is exceedingly difficult; the slope of the natural water surface is made up of a succession of pools and rapids.

A rise of 4 feet at the Gervais Street Bridge is equivalent to a rise of 8 feet at Granby.

At a 5-foot stage steamers can go up the river to Columbia, but under many difficulties, arising from loose bowlders. When steamers reach the Gervais Street Bridge they are at the lower end of a high-level canal, 100 feet wide and 10 feet deep, which extends for 3 miles along Columbia's water front. The canal was built to develop a very large water power.

The bench marks between the railroad and the river gauge were never properly determined. It is said that a series of surveys over this course were made in 1858, but records thereof could not be found. Prof. Benjamin Sloan, of the South Carolina College, at Columbia, S. C., very kindly ran levels back and forth between these two points for this office, and has determined the elevation of the zero of river gauge above sea by connection with South Carolina and Georgia Railroad bench mark.

THE EDISTO RIVER BASIN.

The greater part of the drainage area of the Edisto River lies in Colleton County, S. C., below Edisto, Barnwell County, S. C., where the South Carolina and Georgia Railroad crosses.

The Edisto is formed by the junction of the North and South forks, which unite in the southern part of Orangeburg County, S. C. The South fork, commonly known as the South Edisto, is the main river, and empties into the St. Helena Sound.

Two industries are carried on upon the extreme ends of the Edisto. Timber and lumber is rafted in great quantities down the Edisto and through the inland connections of the Edisto to Charleston. Cross-ties, shingles, etc., are also shipped down the stream, in flatboats, through the Charleston and Savannah Railroad drawbridge, where steam tugs await them to be towed to Charleston, S. C.

The rice interests on the lower Edisto, at and below the Charleston and Savannah Railroad bridge, have reached immense proportions. The rice planters in this section speak in highest terms of the Weather Bureau, which has been the means of saving them one crop of rice since the establishment of the river gauge at Edisto, S. C., in December, 1893.

From the Edisto Island, South Carolina, to a point near Ridgeville, S. C., on the South Carolina and Georgia Railroad, the river runs through an open and swampy country. There is no habitation on this stream between Jacksonboro, S. C., and Edisto, Barnwell County, S. C.

The eastern side of the drainage area runs northerly from Osborn, S. C., to Holly-

hill, S. C.; thence northwesterly to Batesburg, Lexington County, S. C. The western limit of the drainage area runs close to the Edisto River over to Smoaks, S. C.; from here it courses northwestward close to and east of Aiken, S. C.; it then courses northward to Trenton, the southeast portion of Edgefield County, where it ends.

The gauge station within the Edisto basin is located at Edisto, Barnwell County, S. C.

Length of the Edisto River from Guignards Landing to Edisto, Barnwell County, S. C., at the South Carolina and Georgia Railroad bridge, 77 miles; length of the Edisto River from Edisto, S. C., to the Charleston and Savannah Railroad bridge at Jacksonboro, S. C., 144 miles; length of the Edisto River from Jacksonboro, S. C., at the Charleston and Savannah Railroad bridge to the Atlantic, or St. Helena Sound, 39 miles; total drainage area of the Edisto above Edisto, S. C., 1,806 square miles; total drainage area of the Edisto below Edisto, S. C., 1,394 square miles.

The river gauge was erected in December, 1893, and belongs to the Weather Bureau. Length of gauge, 9 feet; width, 0.8 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black, in tenths of feet—the whole feet being represented by brass figures; position of gauge, on south (downstream) side of the South Carolina and Georgia Railroad bridge; elevation of zero of gauge above sea, 127 feet; width of river at Edisto, 360 feet; flood or danger line, 6.5 feet; river overflows at 7 feet. Territory overflowed at this gauge reading, for 2 miles or more on each side of the stream. At a gauge reading of 8 feet the water spreads out for 4 miles or more on each side of the stream. Highest water known, equal to a reading on the gauge of 8.5 feet, July, 1889; lowest water known, equal to a reading on the gauge of 0.0 foot, November, 1887.

Unlike other streams, the Edisto does not rise over 1.5 feet in twenty-four hours. Its ranges are exceedingly small, due to its excessive width above and below Edisto, S. C. Below a gauge reading of 4.5 feet it rises tolerably fast; above this gauge reading it will continue rising at the rate of 0.3 to 0.5 foot per day for about four or five days, remain stationary for several days, and then recede very slowly, the rate of decline seldom exceeding 0.2 foot per day for a week or more.

A copious rainfall of about 1 to 2 inches reported from Columbia, S. C., or Augusta, Ga., is often followed by a rise of 0.8 to 1.9 feet at Edisto, S. C., within three to four days. This increasing volume of water reaches Jacksonboro, S. C., 144 miles below Edisto, S. C., within six days. With more frequent and heavier rainfall over the upper drainage area of this stream the rate of increase is slightly greater. Good results have followed the forecasting of river stages on this stream at Jacksonboro, S. C., upon this basis.

Aside from their value as affording the means for predicting rapid rises, the streams in the third or Piedmont region, in the upper part of the State, and lying to the north and west of the second or "Sand Hill region," possess an unlimited supply of water power for milling purposes. This section of the State has a good average rainfall of 52 to 60 inches per annum, over an area of nearly 30,000 square miles of drainage, with a large storage capacity and a continuous flow of water throughout the year. Advantages of this kind are of considerable value to concerns which depend upon water for their motive power. These, coupled with a good climate, together with unlimited resources for building materials of every description, make this section a very desirable locality for cotton and other manufacturing purposes. It is doubtful if any other State in these United States can furnish a more varied supply of water for motive power. South Carolina is second on the list of cotton mills.

The average fall of water in the streams of the Piedmont region within this State is about 6 feet per mile. There is hardly a stream of any size that will not give fairly good results if properly "harnessed in." As yet only the natural heads due to direct cascades or rapids have been developed, being so numerous that it has not been necessary, except in a few cases, to build dams of any considerable height, and in many cases bolting of timber to ledges was all that was required for damming

streams. Up to the present time only a few of the large powers have been developed, the majority of those used being small ones, ranging from 1,200 horsepower down. The cotton mills, with few exceptions, are located in this Piedmont region. They were established because water power could be obtained cheaper than steam at the time, and when coal was double the price it is now. Not only is good water obtainable, but also cheap wood fuel as well.

There are three flood periods within the basins of the coast region. The first period occurs during January, February, and March, with wonderful regularity, and is caused by the heavy rain and snowfall over the Piedmont region.

The second period occurs during June and July, when the summer showers produce 3 to 6 inches of rainfall in as many hours. This period is irregular, and occurs about once in every three years.

The third period occurs during the three months of August, September, and October, combined, or floods may occur in any one of these three months, between August 15 and October 15. This flood period is, fortunately, quite irregular, occurring once in every three years.

The floods of this period are more to be dreaded than those occurring at any other time of the year.

The rainfall within this period results from the tropical hurricanes which graze our coast and, at times, travel over the State.

The rainfall varies from 6 to 12 inches in one single day. Very often two-thirds of the rice crop will become ruined from floods in ten hours. Cases like these have been known to occur three years in succession.

Since the thorough reorganization of the river service, in August, 1891, thousands of dollars have been saved to the rice planters, stock breeders, steamboat men, and the lumbermen located on the numerous streams in the eastern section of this State.

CHATTANOOGA, TENN.

By Mr. L. M. PINDELL, *Observer*.

The Tennessee river and flood system was first organized and established by the Iron and Coal Manufacturers' Association of Chattanooga in 1880, with Rev. J. W. Bachman as chairman. It was investigated by Lieut. W. E. Wright, Engineer Corps, in 1883, and on his recommendation was turned over to the Signal Service, War Department (now Weather Bureau, United States Department of Agriculture), in the same year. This system embraces the Tennessee, with the following tributaries, viz: Hiwassee, Little Tennessee, French Broad, Holston, Clinch, and Powell. All of these tributaries, except Powell and Little Tennessee, have river stations. The head waters of these tributaries are in the mountains of North Carolina and Virginia, and the Holston, Little Tennessee, and Hiwassee have a rainfall station at their heads. From Chattanooga to the head waters there is a drainage area of 81,600 square miles. The French Broad, Holston, and Clinch rivers are the most important factors in furnishing the Tennessee with her water supply. The Little Tennessee is an important river also, but the rise in this tributary, while of considerable weight of importance, does not affect the main body of the Tennessee River like the Clinch, French Broad, and Holston. The Hiwassee is a very quick and rapid rising tributary; it rises sometimes 10 to 12 feet in one day and falls from 6 to 9 feet the next. If the Tennessee River is high and has begun to fall, and the Hiwassee River begins to rise rapidly, the only effect noticed on the river at Chattanooga is that the falling tendency of the Tennessee is checked, and the rise out of the Hiwassee is hardly noticed. When the Tennessee River is at a moderate stage of about 5 to 8 feet, and heavy rains of 2 to 3 inches falling only over the Hiwassee River, that river will rise rapidly, but only about a 3-foot rise will occur at Chattanooga. Under ordinary conditions—that is, when the ground is fairly moist and does not absorb a very large amount of rain and when the rainfall is general over the entire system, and the rise is about 3.9 feet for every inch at Clinton, 3.6 feet at Knoxville, and 4.9 feet at Chat-

tanooga. If the river is at about 5 feet at Chattanooga, and a general rain falls over the system, the first inch will cause a rise of about 7 feet, the next inch about 5 feet, and, as the river reaches the 25-foot mark, the rise is about 4 feet to an inch. After it passes the 33-foot mark, or danger line, the rise is less, owing to the backwater and the lowlands to be flooded. At a 40-foot stage the average rise is 2.5 feet to every inch of rain. This is when the rainfall is general and steady; but when the rainfall is exceedingly heavy, especially when the river is about 20 feet, the average rise is about 4 feet to every inch of rain at Chattanooga. During the past two years it has been frequently noticed that a general rain of from 1 to 1½ inches makes a very little change in the rivers and tributaries. This is especially so during the summer and fall months, and the only solution that can be given for it is that the ground absorbed a very large portion of the rainfall. It has also been noticed, not only by the observer in charge, but by the river men, that the river has fallen faster than in previous years after a rise, and 0.50 to 1 inch of rainfall does not have much weight in checking its falling tendency. This fact has caused the river men much worry, as it has destroyed all their calculations, and caused trouble in navigating the river during low or moderately low water. It has been noticed that heavy rain falling over the tributaries on the south side of the Tennessee River causes only a slight rise at Chattanooga, but when the heavy rain falls over the northern half, or entire system, the rise is greater or more rapid than in former years, and it is the opinion of all interested that the cause is directly attributable to the clearing up of the country and forest, leaving large fields of exposed lands, from which the water runs into the channel of the river without any material obstruction. When the river reaches 36.5 feet at Chattanooga the people in the lowlands begin to move. At 43-foot stage the river backs up Chattanooga Creek, over the commons near Rouh's cotton mill, and covers the Government road for nearly 300 feet to a depth of 2 feet; it crosses William and Long streets, and the blocks from Montgomery avenue, between Williams and Long, are covered to a depth of 2 to 3 feet; covers Cowart street at one point, and reaches lower floor of most of the houses; Boyce street is covered to a depth of 2 to 3 feet, and lower end of Water street is under water. The river extends one-third of a mile from river banks in Hill City, at 42 feet. When the river is 34 feet at Loudon the lower portion of the town is 20 feet under water. Thirty-foot stage at Chattanooga covers the Chattanooga Island near the river gauge. A 40-foot stage puts the Chattanooga Creek on the floor of the Whiteside Street Bridge. The river begins to run over the railroad track in front of the Loomis Hart mill at 36.9 feet. The Loomis Hart brick warehouse is surrounded by water at a 38-foot stage. Water flows over Montgomery avenue at Standard Oil Company's place at 41.3-foot stage. At a 51.6-foot stage water is over Ninth street in front of Read House. During the past summer and the drought several local storms have occurred, with heavy rainfall over some of the tributaries, which have caused sudden and expected rises in the river at this point (Chattanooga). It appeared, from the muddy condition of the water, that the rain fell so heavily that it all ran off into the river, and the ground absorbed very little. The logmen watch the river and rainfalls very closely, and when heavy rains occur, enough to cause a good rise of 10 to 15 feet, telegraph their agents on the head waters, and have their rafts floated down at once. The inclosed table, No. 1, shows the average rise for every inch of rainfall at each station in the Tennessee river and flood system during each freshet, from 1880 to 1893, inclusive, and has been used to great advantage by the observer in charge in making estimates of rises in the river up to 30 feet. Table No. 2 shows the error in computing rises from amount of rainfall by use of the mean average rise per inch of rain. The table is only given to show how great an error can be made by depending upon the amount of rainfall entirely, without considering the condition of the ground and the general character of the rainfall, whether it is uniform, or comparatively so, over the system, or not. It has been proven, by tests and observations by the City Water Company, that between 20 and 30 feet during a rise the river is muddier and contains more quick-

sand, dirt, leaves, and other obstructions than when it is higher, and this sediment, mud, etc., extends from the top to the bottom, as proven by the filters of the water company; they have become clogged up and would not work, and the superintendent, Mr. C. D. Barstow, has informed me that it is astonishing to see the amount of quicksand and leaves taken from the filters and around the suction valve after the river falls. The discharge of the river when rising, at 25 feet, with a cross section of 36,648 square feet, is 156,187.264 cubic feet per second, and when falling, at the same height, viz, 25 feet, the discharge is 151,659.945 cubic feet per second. These measurements were made from the Hamilton County Bridge, on May 5 and 8, 1893, by L. M. Pindell, observer Weather Bureau.

I.—Table showing average rise for every inch of rainfall at each station during each freshet from 1880 to 1893, inclusive.

Date.	Chattanooga.	Rockwood.	Kings-ton.	Charles-ton.	London.	Clinton.	Knox-ville.	Straw- berry Plains.	Lead- ville.
	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>
March, 1880	2 5	.....	.....	.....	.....	.....	.....	.....	.....
January, 1882	3 0	.....	.....	.....	.....	.....	.....	.....	.....
January, 1883	4 6	.....	.....	.....	.....	.....	.....	.....	.....
February, 1884	4 7	.....	3 4	4 1	2 5	2 3	2 3	.....	3 8
March and April, 1886	3 9	.....	3 9	2 7	3 3	3 9	3 3	3 5	3 6
March, 1884	7 6	4 8	5 2	5 1	4 7	4 4	3 8	.....	4 7
February, 1891	3 6	3 3	4 0	4 8	5 2	4 3	5 6	2 9	.....
March, 1891	5 1	3 1	2 8	3 3	2 8	2 9	2 4	1 4	.....
January, 1892	5 9	4 1	4 9	4 5	4 8	4 7	6 6	3 9	.....
April, 1892	5 2	2 9	4 0	2 8	2 0	3 8	2 7	2 2	.....
February, 1893	4 5	3 0	3 2	3 0	2 6	4 2	2 3	2 8	.....
Mean average.....	4 9	3 6	3 9	3 8	3 6	3 9	3 6	2 8	4 0

II.—Table showing the error in computing rises from amount of rainfall by use of the mean average rise per inch of rain, for every freshet that has occurred since 1884.

Date.	Chattanooga.	Rockwood.	Kings-ton.	Charles-ton.	London.	Clinton.	Knox-ville.	Straw- berry Plains.	Lead- ville.
	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>	<i>Ft. In.</i>
February, 1884	+ 1 2	.....	+2 8	- 1 3	+ 5 8	+ 8 4	+ 5 2	.....	+0 0
March, 1884	-12 2	-6 2	-6 2	-6 2	-4 9	-5 2	-3 0	-0 8	-1 5
April, 1886	+11 2	.....	-0 2	+11 7	+ 2 3	+ 2 1	+ 2 8	+ 3 4	+1 9
February and March, 1890	-13 9	-2 8	-0 2	- 2 6	- 3 7	-3 2	-1 0	2 9	.....
February, 1891	+ 8 8	+1 6	-0 4	-3 6	-4 9	-1 5	-6 0	-0 6	.....
March, 1891	- 1 0	+3 1	+6 3	+ 2 5	+ 3 9	+ 5 8	+ 5 5	+ 5 6	.....
January, 1892	- 4 9	-2 2	-4 1	-3 9	- 5 5	-2 9	-9 1	-3 5	.....
April, 1892	- 4 8	+3 3	-0 5	+6 3	+10 0	+0 5	+4 1	+2 6	.....
February, 1893	2 7	+3 4	+4 0	+ 3 5	+ 5 8	-2 1	+7 9	+0 8	.....
Average error.....	6 4	3 4	2 7	4 5	5 2	3 1	4 8	2 7	.....

DAVENPORT, IOWA.

By Mr. F. J. WALZ, Observer.

The first tributary of any consequence entering the Mississippi River is the Minnesota, which enters at Fort Snelling, about 6 miles above St. Paul. This river has a drainage area of 12,119 square miles.

From St. Paul to Prescott, Minn., a distance of 30 miles, the Mississippi River is rather sluggish, with easy current and high banks. The river has been much improved for navigation within the past few years by the putting in of numerous wing dams and cutting off sloughs. There is from $3\frac{1}{4}$ to 4 feet of water in channel at lowest water stage.

The St. Croix River, with a drainage area of 7,146 square miles, enters the Mississippi at Prescott from the west. From this point to Lake Pepin the river runs in a sluggish current, but with very good navigation and much improved, through a valley of from 2 to 4½ miles wide, keeping well to the east side of the valley. About 6 miles above Lake Pepin the river crosses the valley and spreads out through a number of channels, forming numerous sloughs and small lakes.

Lake Pepin is a lake formed in the Mississippi River, and is about 20 miles long and from 2 to 3 miles wide and varies in depth from 20 to 90 feet. It contains no current.

At Reads Landing, just below Lake Pepin, the Chippewa River, with a drainage area of 9,708 square miles, enters the Mississippi. From this point to where the Wisconsin enters, a distance of 151 miles, the Mississippi runs through a sandy valley of some 2 miles in width and high, picturesque bluffs, with a moderate current, winding about and crossing from side to side of this valley, forming a very crooked stream, with alluvial banks and many islands and sand bars.

In this section is the most obstructed part of the river, though it has been considerably improved, and the greater part now furnishes good navigation, and a 4-foot depth is maintained in channel at low-water stage. The Chippewa carries down from Wisconsin much sand and deposits it over this section, which is the cause of a great deal of trouble to navigation and improvement. A large part of the river business begins from the Chippewa, as immense log booms are constructed in that vicinity from which rafts are made up, and out of which springs a great portion of the upper river traffic and industries.

The Black River, with a drainage area of 4,601 square miles, enters at La Crosse, Wis., 72 miles from the Chippewa. From this point to the Wisconsin River the Mississippi is a very sluggish stream and covers almost the whole valley, which is from 2 to 4 miles wide. This section is now considered the most troublesome and hardest for navigation, though it has been much improved by the cutting off of a number of the sloughs, thus confining the water more to the main channel.

From the Wisconsin to the Rock Island Rapids the Mississippi continues with gentle current, crossing and recrossing the valley, which narrows to about 1 to 1½ miles in width, to the Galena, a distance of 70 miles, and then widens out to 4 to 5 miles in width.

Over the Rock Island Rapids, which extend from Le Claire, Iowa, to Davenport, Iowa, a distance of 16 miles, the Mississippi narrows to about three-fourths of a mile in width, and has a swift current, running from 6 to 7 miles per hour. In this distance there are numerous chains of rocks, which, in connection with the swift current, makes navigation dangerous, and necessitates the employment of special pilots for the rapids. These rapids have been much improved for navigation by cutting channels through the rock chains and by a system of wing dams put in to distribute the fall and throw the water into the channels. By the extension of these improvements navigation is being made safer each year and a 4-foot depth maintained at low-water stage.

From the rapids to Muscatine the river widens out and becomes a shallow stream with slack current. Navigation is troublesome in some places during low water, but is being improved. The river valley varies from 1½ to 2 miles in width between the bluffs.

Rock River, with a drainage area of 9,692 square miles, enters the Mississippi 1 mile below Davenport.

Storage reservoirs.—Several storage reservoirs have been constructed at the head waters of the Mississippi River, the principal being at Pokegama Falls. The low-water volume of the Mississippi at Pokegama Falls varies from 500 to 1,000 cubic feet per second, depending on the meteorological conditions. The increment of the volume due to the reservoir water is felt at St. Paul in from seven to ten days, depending upon the stage and current at the time, and causes a rise in the stage of

the water at St. Paul of from 0.7 to 1.2 feet, which is maintained. This rise, however, is scarcely appreciable below Lake Pepin.

Commerce and navigation.—The most important business carried on in connection with the navigation of the Upper Mississippi River and its principal tributaries is the lumber trade. Along the river are some 60 large sawmills, which manufacture over 2,000,000,000 feet, B. M., of lumber, and 750,000,000 shingles and lath, the larger part of which is carried for greater or less distance on the Mississippi River, either as logs or lumber.

The average yearly tonnage of the Upper Mississippi River for the past eight years was 3,550,000 tons, and 150,000 passengers, not including those of ferry and excursion boats.

I.—Drainage area of the Upper Mississippi River at its principal tributaries to the mouth of the Rock River.

	Square miles.		Square miles.
1. Area above St. Paul.....	19,903	9. Upper Iowa	1,376
2. Minnesota River.....	12,119	10. Yellow.....	652
3. St. Croix	7,146	11. Wisconsin	12,867
4. Cannon.....	1,690	12. Turkey River.....	1,589
5. Chippewa	9,708	13. Maquoketa River	2,209
6. Zumbro	1,604	14. Galena River	1,895
7. Black	4,601	15. Wapsipinicon River.....	2,957
8. Root	1,823	16. Rock River	9,692

II.—The total drainage area of the Mississippi River from Rock River northward, including all creeks and small rivers, is 93,000 square miles.

	Distance from St. Paul.	Distance apart.	Difference in elevation (above sea level).	
			Standard high water.	Standard low water.
	Miles.	Miles.	Feet.	Feet.
Red Wing, Minn.....	52	22	.....	14. 87
Prescott, Minn.....	30	30	.....	15. 25
Reeds Landing, Minn.....	84	32	1. 35	. 85
Winona, Minn.....	125	41	22. 06	24. 30
La Crosse, Wis.....	156	81	13. 55	12. 58
McGregor, Iowa.....	231	75	.....	22. 31
Dubuque, Iowa.....	290	59	15. 93	19. 98
Sabula, Iowa.....	337	47	15. 93	14. 10
Clinton, Iowa.....	358	21	5. 49	5. 40
LeClaire, Iowa.....	381	23	10. 03	3. 37
Davenport, Iowa.....	397	16	15. 93	20. 74
Muscatine, Iowa.....	426	29	12. 89	11. 09

GAUGE RELATIONS FOR SEVERAL REPORTING STATIONS BETWEEN ST. PAUL AND DAVENPORT, PLATTED WITH TRIAL INTERVALS IN ACCORDANCE WITH THE METHOD OF MR. JAMES A. SEDDON.

. Up to the crest on both the rising and falling stages, each point in a flood wave at the upper gauge must have its period, after which the same value of discharge—and hence the true equivalent of its gauge height—would be found at the lower gauge, due allowance being made for intermediate tributary increment, or when the increments from tributaries are immaterial. If, in plating a trial gauge relation, the assumed time interval were less than the true period, or too short, then on the rising stage the lower gauge values taken would not have had time to rise to their true equivalent value, and would be too small in proportion to the rapidity of the rise. In the same way on the falling stage, the lower gauge values would not have fallen enough, and would be too large in proportion to the rapidity of the fall. By

the same reasoning, if the trial interval had been too long, the lower gauge values would have been too large on the rising and too small on the falling stages; and if between the trial intervals an interval is found which causes the relation to plat with the rising and falling stages coinciding throughout, or following nearly the same line, it shows that this interval is the true time interval of flood movement between the two gauges.

As this flood (May 15 to June 6, 1894) was a typical one, in that it was almost entirely caused by heavy rains in one or more showers very close together (May 15 to 18) over Minnesota and Wisconsin, the upper drainage area of the Davenport district, and consequently the greater part of the water passed down the river in one continuous flood, thus producing fair gauge relations, I have with care platted it in accordance with the above simple law, believing that a nearly true time interval for the reaches between the reporting stations would be found.

Of course, in applying these time intervals in forecasting river stages, due attention would have to be paid to rainfall distributed over the drainage area, and the increment from intermediate tributaries. The effect of the latter in this instance is plainly shown in the platted relations by their inclination and straightness.

DUBUQUE, IOWA.

By Mr. T. W. RUTZ, *Observer*.

The Mississippi River for a distance of about 60 miles north of Dubuque, Iowa, is bounded on the Iowa side by the counties of Allamakee, Clayton, and Dubuque; on the Wisconsin side by Crawford and Grant counties. South of Dubuque, on the Illinois side, the river is bounded by the county of Jo Daviess, and on the south Iowa side, by the county of Clinton.

Bluffs from 50 to 150 feet high form the embankments of the river, generally rising almost perpendicularly from the level of the water, appearing like palisades covered with trees and underbrush.

The many creeks and small rivers find their outlet into the Mississippi through ravines which through ages have been cut down to the bases of the bluffs.

These high embankments of the river are a natural protection against floods and the increased volume of water which at times the river pours down from the upper country. As the farming lands are mostly some distance inland from the river, the damage from high water is not so great as might appear, excepting in the immediate vicinity of and at the city of Dubuque, which latter place covers a more exposed flat territory and has been on several occasions visited by disastrous inundations.

The principal smaller and larger rivers tributary to the Mississippi in the counties north of Dubuque are the upper Iowa, in Allamakee County, and the Turkey River, in Clayton County, Iowa. Below Dubuque, in Jo Daviess County, Ill., the Galena empties into the Mississippi, and on the opposite side the Maquoketa, in Jackson County, Iowa, and the Little Maquoketa, just above Dubuque, and on the east side the Wisconsin River, in Crawford County, Wis., and the Grant and Platt rivers, in Grant County, Wis. Besides, these numerous streams and creeks have their tributaries, and in the early spring, after great snowfalls, these waters often assume formidable proportions, and if a season of rains adds to these volumes of water the Mississippi rises and overflows its banks in the bottom lands and great damage is often the result. The immense pine forests of Wisconsin are generally covered with great depth of snow, which does not melt until late in the spring, often as late as April and May, and as the rain season sets in about that same period it results in floods, which the great river sends down from Minnesota and Wisconsin. Thus while the country above Dubuque is generally protected by the high rocky embankments, in Jo Daviess County, Ill., opposite and below Dubuque, the hills disappear and recede a great distance from the river, leaving a low stretch of land for miles south exposed to floods. Dubuque has experienced several visitations from high

water, particularly in the years of 1880, 1881, and 1888, when the entire lower part of the city, with its manufacturing district, sawmills, and lumber yards, has been submerged, causing great damage.

In 1880 the highest water mark was 28.8, and in 1881, 21.2, and in 1888, 21.7.

In late years the authorities have improved the river banks at Dubuque by the use of sand pumps, which take the sands from the bottom of the river and pumps it on land, raising the banks to greater height and forming excellent protection against floods of moderate proportions.

The river has been known to rise to a great height in midsummer when continuous heavy rainfalls swell the smaller waterways into greater proportions, and so increasing the volume of all the tributaries of the Mississippi sufficiently to cause a great rise of water.

Immediately below Dubuque, about 2 miles, is the little Catfish Creek, which originates as a small brook in Dubuque County and flows through quite a large bed with high embankments through a hilly wooded country, emptying into the Mississippi after passing through the village of Rockdale, 10 miles south of Dubuque.

During the night of the 3d of July, 1876, a tremendous thunderstorm visited this city and neighborhood, lasting with unabated fury from July 3, 10 p. m., until the next morning at 4 a. m., during which time an uninterrupted rainfall inundated the entire vicinity.

On this occasion the usually diminutive Catfish Creek had grown into the proportions of a good-sized river, full to its high banks, carrying houses, bridges, barns, and cattle along its surface and drowning 44 people of Rockdale, sweeping away almost the entire little village. This incident shows the effect of great rainfalls upon small bodies of water in this vicinity and the destruction which may be caused thereby.

As the country becomes more populated and settled greater precaution is taken in guarding against these floods, by improving the banks of the rivers and placing buildings or planting crops where there is less danger from flood disasters.

FORT SMITH, ARK.

By Mr. J. J. O'DONNELL, *Observer*.

The rivers and creeks of this vicinity tributary to the Arkansas, for a distance of 141 miles west and 150 miles east of Fort Smith, viz, from Fort Gibson to Dardanelle, Ark., are described below.

West of the Ozark Mountains and on the north side of the Arkansas River are the following streams, distant from Fort Smith: Camp Creek, 8 miles; Sallisaw Creek, 65; Vian River, 80; Illinois River, 100; Greenleaf River, 110; Grand River, 140; Verdigris River, 141. Those creeks (excepting Illinois, Grand, and Verdigris) have their head waters in the Cherokee Nation, varying in width from 50 to 100 feet, with rock-slate and flint bottom. They have a very rapid current, being all known as mountain streams. The Illinois River, with its tributaries, drains part of Washington, Crawford, and Benton counties, Ark. It is 150 feet wide at its mouth, with banks from 20 to 25 feet high. It is not navigable, but logs are rafted on it for a distance of 100 miles from its mouth. The current is rapid—about 8 or 10 miles an hour when half-bank full. It has a rock-slate bottom.

The Grand River, with a gravel bottom, is 500 feet wide at its mouth, with banks 25 feet high; is navigable for 40 miles to the junction of Neosho and Spring rivers. The Neosho, the principal stream, is navigable for 50 miles farther up; the current of the river when flooded, was measured by Signal Service Observer Campbell and Captain Blakely in 1882 to be 12 miles at Fort Gibson, 2 miles from its mouth. This river has its head waters in Kansas, and drains the western parts of McDonald, Newton, and Jasper counties, Mo.

The Verdigris River is in close proximity to the Grand River and is as large, emptying its waters 1 mile westward; banks about 20 feet wide. It is navigable for 12

miles to the falls, where a ledge of rocks about 4 feet high cross the river. Above these falls it is navigable for 5 miles for flat-bottom boats of 3 feet draft.

On south side are the Porteau at Fort Smith, 300 feet wide, rock bottom, west bank 20 feet for 5 miles from its mouth. Crozier Creek, 30 miles west, and Lan Bois, 50 miles west, etc., streams of inconsiderable size, from 40 to 50 feet wide.

The Canadian, 95 miles west, is about 1,000 feet wide, with sandy bottom, banks 22 to 25 feet, is navigable 50 miles to the junction of North and South forks and to Eufaula on North Fork, 8 miles farther. No information can be procured regarding the Cimarron River.

Relative to floods and high water in the Arkansas River, it is claimed that west of Great Bend floods do not materially affect the river at this place. The principal floods come on the north side from the Illinois, Grand, and Verdigris; on the south side, the Porteau and Canadian. It can easily be discovered when the rise comes out of the Canadian, it being very muddy, with a reddish tint, leaving a deposit of mud and clay of from 6 to 20 inches on the wharf and gauge. This remains on the wharf until washed off by rain or a rise from the Porteau or north-side streams.

The Porteau has head waters in Porteau Mountains in Scott County, 50 miles south. When the Porteau has 17 or 18 feet of water, and there are 4 to 6 feet on gauge, it will raise the gauge to 16 feet. When the Canadian is bank full and 6 feet of water on gauge, it will be raised to at least 20 feet. The Grand and Verdigris rivers, together with 17 or 18 feet of water, about equal the Canadian. When the Canadian, with either of the Illinois, Grand, or Verdigris, comes out strong with about 16 or 17 feet, and there is 5 or 6 feet on gauge, the Arkansas bottom lands will overflow for a distance of 100 miles west and east. When all streams come out the water is backed in the Arkansas above Fort Gibson and the bottom lands will be flooded several feet. High water is much more frequent from the Canadian River country than any other section.

East of Fort Smith the principal creeks on north side, distant from Fort Smith, are Lees Creek, 9 miles, 200 feet wide with 10 feet fall in one-quarter mile from its mouth; Frog Bayou, 45 miles, 200 feet wide; Mulberry Creek, 60 miles, 200 feet wide; Piney Creek, 130 miles, 250 feet wide; Illinois Bayou, 140 miles, 250 feet wide. These streams have head waters in Boston Mountains, northwestern Arkansas, and drain a large area of prairie country. Having a considerable fall, they send off large volumes of water very rapidly. There are none of them navigable for any great distance. On south side are Vashgrass Creek, 25 miles, and Shoal Creek, 120 miles, streams similar to those on north side, but not quite as large, being only about 150 feet wide.

HANNIBAL, MO.

By Mr. WM. A. MUNGER, of Hannibal, Mo.

I estimate the watershed of the Missouri side as about 100 miles in length by an average of, say, 55 in width, or 5,500 square miles. The chief waterways that carry the water to the Mississippi, beginning on the north, are the Fox, Wyaconda, North and South Fabius, North and South rivers in Marion County, the Salt, and the Cuivre.

On the east side, in Illinois, the watershed extends from opposite Keokuk to the mouth of the Illinois, 100 miles in length by an average of 20 in width, or 2,000 square miles. This gives a total of about 7,500 square miles' watershed between south of Iowa line and the junction of Illinois and Mississippi rivers. The chief portion of the water from the Illinois shed here mentioned enters the Mississippi River at lower portion of this district, owing to the Shy levee. It is my observation that when the Mississippi River is at a fair stage, say, 7 to 10 feet of water, that a stream the capacity of the Des Moines is able after a good rainfall of, say 3 inches, to discharge sufficient water to raise the stage at Hannibal 3 feet.

It is the accepted rule here that at high stage of river a rise travels at the rate of 30 miles in twenty-four hours, or 1½ miles per hour. We noticed the past season that on June 4 the Keokuk high stage was 11 feet 4 inches, and on the 6th, at Hannibal,

it was 12 feet 2 inches, and, as no local rains occurred, this shows a difference in gauge at the two places of 10 inches. This is perhaps owing to the bridge and levee forcing the water into a more confined channel. In no case during the past twenty years have we had extreme high water, 20 feet and over, unless preceded by heavy rains on the upper river above Davenport. If about ten days or two weeks later there are heavy rains in central and southern Iowa, the meeting of flood waters in vicinity of Keokuk never fails to cause trouble here and bring extreme high water; in fact, in no case can I recall a break on our levee but that we considered the water from the Des Moines was the cause of it.

HARRISBURG, PA.

By Mr. FRANK RIDGWAY, *Observer.*

The Susquehanna River rises in the southwest portion of New York State, and, from the head waters to Sunbury, Pa., it is called the North Branch, which has a watershed of about 12,000 square miles. The northern half of Bradford, the whole of Tioga, and nearly the half of Potter County send their waters into the Susquehanna through the Chemung, which has a drainage of 2,518 square miles and empties into the North Branch 2 miles below Athens, in Bradford County. In addition to this, the river receives waters from the southern half of Bradford and northern half of Sullivan counties through its numerous tributaries. These empty into it as it flows through Bradford, Susquehanna, Lackawanna, and Luzerne counties, which contribute their entire drainage to the North Branch. The whole of this enters the Wyoming Valley through a narrow gorge in the mountains 9 miles above Wilkes-barre. As this valley is only 3 miles wide, with high, precipitous mountains on both sides and with an outlet of but 600 feet, which is also embraced by almost perpendicular mountains, its residents, who number about 100,000, are alarmed at the approach of flood seasons, at which times the river has been known to rise 24 feet in as many hours.

In the spring of 1846 the lower portion of Bloomsburg was completely submerged on account of an ice jam near Catawissa, 6 miles south, and it has since been once or twice partially inundated from the same cause. The bed of the North Branch is ample for all the water and ice that ordinarily pass through. Fishing Creek, which rises about 40 miles west of Bloomsburg and discharges into the North Branch 2 miles south of that place, is a wild stream, rising frequently from 13 to 14 feet above low-water mark and carrying away portions of the farms and timber along its banks. The southern side of the North Branch is well protected by mountains from Nanticoke to Danville and the North Branch Canal parallels it on the north side. I have devoted most of my attention to the West Branch, which is the most troublesome stream in the State and causes the most damage. It rises in Cambria County and drains an area about 7,020 square miles, or about one-ninth that of the State. This area lies at an elevation of from 430 to 2,300 feet above sea level, and its population is about 330,000, or 47 per square mile.

The condition of the river for the passage of water is bad. When the West Branch Canal was built, in 1830, dams were built at Sunbury, Lewisburg, Muncy, and Lockhaven; and when the lumber industry first assumed a prosperous magnitude, in 1860, a dam was built at Williamsport. Since then the river has been given over to the lumbermen. A line of boom piers, 7 miles long, was built in the pool of the dam above Williamsport, and others have been constructed in the river at Lockhaven and other points. All of these are more or less of an obstruction to the passage of water. Logs are worked out of the smaller streams by the process known as "splashing," which consists of clearing the streams of all impediments such as fallen timber, jams of driftwood, rocks, etc. In a dam at the head waters a large body of water is impounded, which, when suddenly released, washes the logs out of the

stream that ordinarily has not enough of water to float them. This clearing forces the water to the main affluents much more quickly than formerly when the streams contained innumerable natural dams or barriers made of fallen timber, driftwood, etc. These retarded the flow of the water to a great extent, so that the work done by the lumbermen has had the effect of accelerating the current at the head waters and retarding it in the main river. In order to improve present conditions the reverse of this should be done.

The condition of the watershed at present is such as to cause alarm. The ice in the river passed out below Williamsport during the thaw early in January, but ice is gorged farther north at Linden and the cold weather has closed the river again tighter than before. The ground throughout the entire watershed of the Susquehanna is covered by from 1 to 3 feet of snow, and a sudden thaw is likely to produce a serious flood.

The accompanying profile (fig. 1) shows the fall of the river between the head waters and Havre de Grace, a study of which shows conclusively why the range between high and low water is greater in the vicinity of Williamsport than at any other point above or below. The rate of fall of streams above Lockhaven is from 5 to 50 feet per mile, while from Lockhaven to Williamsport it is 1.59 feet per mile; from Williamsport to Sunbury, 1.67 feet per mile; thence to Harrisburg, 2.10 feet per mile; and from Harrisburg to Havre de Grace, 4.83 feet per mile. It will be seen that the fall between Lockhaven and Williamsport is the least of any, and as this is the stretch of river where the principal torrential streams debouch into the main valley, the water is piled up faster than the river can carry it away and it overflows its banks before it can find other outlets.

Table I, presented herewith, gives to each basin the approximate amount of forest, tilled land, and land that has been cut over and has remained unimproved. Absolute accuracy is not claimed for it, as no reliable data are at hand from which to compile it, but it is as accurate as can be made without any actual survey. It will be observed that only about one-fourth of this large area remains in forest, and to such a pronounced change from the original conditions the frequency and extent of floods must, in a great measure, be attributed.

With a proper system of forest conservation we should have no difficulty in maintaining fully one-half of this area in forest; and until a larger area is maintained, and something is done to check the rapid destruction of what yet remains, more extensive floods than those we have ever had may be expected.

Tables II and III show the percentage of whole area above Muncy and above Williamsport. Ninety-three per cent of the whole area is above Muncy. Below that point the basin narrows, and as the capacity of the channel becomes greater the range between high and low water is not so great.

Table IV contains a list of the floods on the river, compiled from the most reliable data obtainable. The great flood in the West Branch and main river was that of June 1, 1889, which reached 33 feet at Williamsport, about 35 feet at Muncy, gradually decreased to 24 feet at Sunbury, rose to 27 feet 1 inch at Harrisburg (this increase coming from the Juniata at Clarks Ferry), reached 29 feet at Lockhaven, and 18 feet at Clearfield. The flood of 1894 averaged from 2 to 3 feet less than that of 1889. The flood of 1884 was greater on the North Branch than on the West Branch. It would appear from this list that the floods on the West Branch have been increased in magnitude, but this is not the case. On the main river between the mouth of the Juniata and Sunbury the greatest floods were those of 1786 and 1846. The floods of 1889 reached about the same height on the West Branch, and that of 1894 was about 2 feet less, but were probably not so high as those of 1786 and 1846.

The greater floods can be accounted for from the fact that the maximum flow of the North and West branches rarely arrive simultaneously at their junction at Sunbury. In fact, the West Branch was so much higher in 1889 than the North Branch

that logs and driftwood from the West Branch floated several miles up the North Branch. A flood on the river below Sunbury does not, therefore, become serious unless the path of the storm is such that the flooded waters from both branches reach Sunbury at the same time.

The waters of the Juniata and West Branch, however, are more apt to arrive at Clarks Ferry at the same time. This conjunction caused the trouble in 1889. It is rare that the Juniata waters do not arrive at the Susquehanna and Clarks Ferry and subside before either the North or West Branch waters arrive. The damage done by the Juniata is confined to its own banks. It has a drainage of 3,223 square miles.

A study of the list of floods seems to dispose of one conjecture that has been current since our last two floods. Many people have held that a flood of any magnitude has been unusual in the past during a season when trees were in foliage, and they have attributed the present changed conditions to the destruction of the forests. The records of floods, however, show that they have been distributed throughout all seasons of the year, and it is not likely that the destruction of the forests has had any effect on the time of year when floods may be expected, but the effect of this denudation is to increase the height of floods when they do occur. This theory is more plausible when it is considered that most of the timber in this watershed was not of deciduous nature. To obtain some indication of the height of water to expect at Williamsport, the height of water reported at Clearfield and at Harrisburg has been doubled. It depends entirely upon the difference in time between the arrival of the high water from the North and West branches at Sunbury and from the Juniata at Clarks Ferry. This method is crude, and is correct only when the amount of rainfall and other conditions are the same throughout the watersheds.

In order properly to predict floods observers should be located in each basin of the watersheds, gauges should be placed at a number of places on the river between Sunbury, at the head waters, and on each of the main affluents. Floods should be predicted very closely from the reports of these observers. To cover the territories properly observers should be located at Sunbury, Lewisburg, Williamsport, Jersey Shore, Lockhaven, Renovo, Keating, Karthaus, and Clearfield. On the main river they should be placed at Hughesville; on the Muncy Creek, at Logan Valley and Ralston; on Lycoming Creek, at Waterville and Slate Run; on Pine Creek, at Driftwood and Emporium; on Bennets branch of the Sinnamahoning, and at Howard and Milesburg, on the Baldeagle. Accurate telephone and telegraphic communication would be an essential feature of this system.

In the flood of 1889 the maximum flood occurred at Williamsport fifteen to sixteen hours after the cessation of the rain. In the flood of 1894 the rain was practically continuous for two or three days before and after the flood, although the heaviest rain was the day before. The maximum flood occurs at Williamsport from eight to twenty-four hours after it occurs in Clearfield; at Sunbury about sixteen hours after Williamsport, and at Harrisburg from six to eight hours after Sunbury. It is 112 miles from Williamsport to Clearfield; 40 miles from Williamsport to Sunbury, and 56 miles from Sunbury to Harrisburg.

The velocity of the river being from 6 to 10 miles per hour, it will be seen that the current and the maximum flood move at about the same rate. From Clearfield and Williamsport to Sunbury the currents move very much faster than the maximum; in fact, during the last two floods the water remained at a maximum from three to four hours, then started to fall very slowly.

I. Table showing the amount of forest in the basins of the West Branch watershed.

Name of basin.	Forest.		Tilled land.		Land cut over.		Total.
	Square miles.	Per cent.	Square miles.	Per cent.	Square miles.	Per cent.	
Clearfield	225	15	600	40	675	45	1,500
Sinamaboning	303	30	150	15	557	55	1,010
Kettle	168	40	42	10	210	50	420
Baldeagle	212	20	318	30	530	50	1,060
Pine	312	25	875	30	563	45	1,250
Lycoming	80	20	120	30	200	50	400
Nippenose	40	25	56	35	64	40	160
Loyalstock	196	40	122	25	172	35	490
Muncy	72	30	84	35	84	35	240
Chillisquaque	33	15	132	60	55	25	300
Whitdeer	40	15	108	40	122	45	270
Total	1,681	24	2,107	30	3,232	46	7,020

II. Area above Williamsport, Pa.

	Square miles.	Per cent.	Percentage of the whole watershed.
Forest	1,340	23	80
Tilled land	1,661	29	79
Land cut over	2,799	48	87
Total	5,800	100	83

III. Area above Muncy.

	Square miles.	Per cent.	Percentage of the whole watershed.
Forest	1,608	24	96
Tilled land	1,887	29	88
Land cut over	3,055	47	94
Total	6,530	100	93

IV. List of floods in the Susquehanna River.

Date.	Height.	Remarks.
February, 1692	No record	3 feet higher than 1783.
February 12, 1731	do	
February 17, 1783	do	
January 28, 1787	do	
January 28, 1744	do	
January 28, 1753	do	The ice flood (on North Branch). Called "pumpkin flood."
January 7, 1762	do	
January 7, 1772	do	
May 15, 1784	do	
October 5, 1788	do	
October 1, 1787	do	Also called "pumpkin flood."
April 1, 1800	do	
April 23, 1804	do	
November 20, 1810	do	
August, 1814	do	
July 20, 1824	do	Water rose higher than ever remembered by oldest residents.
May 5, 1831	do	
June 28, 1829	do	

IV.—List of floods in the Susquehanna River—Continued.

Date.	Height at Williamsport.	Height at Harrisburg.	Remarks.
July 4, 1832.....	No record.....	No record.....	Greatest since 1786, on main river; 3 or 4 feet higher than any previous rise.
May 17, 1834.....	do.....	do.....	
February 12, 1837.....	do.....	do.....	
May 13, 1846.....	do.....	22.2 feet.....	
October 9, 1847.....	25 feet.....	No record.....	
August 19, 1851.....	No record.....	do.....	
February 7, 1853.....	do.....	do.....	
September 23, 1861.....	25 feet.....	do.....	
March 17, 1865.....	27 feet.....	24.11 feet.....	
June 1, 1889.....	33.5 feet.....	27.1 feet.....	
May 21, 1894.....	31 feet.....	25.7 feet.....	

KANSAS CITY, MO.

By Mr. P. CONNOR, *Local Forecast Official.*

Danger begins at 21 feet. At that stage the river begins to encroach on the west bottoms and Harlem, a small village directly north of this city on the opposite side of the river. A 24-foot stage will submerge Harlem and the west bottoms, and cause an overflow in the packing house, wholesale, and manufacturing districts located in what are known as the west bottoms of the city.

An overflow from the regular spring rise is never anticipated, unless coincident with heavy rains in the territory continuous to the river to the South Dakota line. An overflow is most likely to occur in May, June, or early in July.

An overflow is not looked for in the Kansas River, which empties into the Missouri at this place, from continuous heavy rains, while the Missouri is at a comparatively low stage; but with a high stage in the Missouri an overflow is possible in the Kansas, or "Kaw," as it is commonly known, due to heavy rains in northeast Kansas. An overflow will not occur in Armourdale, Kans., until the water reaches a level corresponding to 26 feet on the Missouri gauge, and the bottoms of Kansas City, Kans., until it reaches 28 feet. This information relating to Armourdale and Kansas City, Kans., has been obtained from the city engineer of the latter place.

The river changes at this place are not of a complex character, but are gradual from day to day, depending upon the supply from head waters, considered in connection with the heavy rains in the territory alluded to.

KEOKUK, IOWA.

By Mr. FRED. Z. GOSWICK, *Observer.*

The Des Moines Rapids extend 7 miles north of station, the bottom of solid limestone rock, with reefs rising to surface, channel very crooked, and has a fall of 18 feet in the 7 miles.

The rapids channel is navigable for rafts and steamboats when there is a stage of 4 feet of water in the river gauge at Keokuk. Below that stage navigation is dangerous, and at 3½ feet the rapids are impassable for any but very light-draft boats.

A steamboat canal, built by the Government and operated by the United States Engineer Corps, extends the entire length of the rapids along the Iowa shore, and consists of two levels with three locks.

The larger part of the river traffic is the rafting of lumber and logs from the northern pineries to market centers along the river. Rafts containing several million feet of lumber each, propelled and steered by attendant steamboats, are run over the rapids when the stage of water will permit, making the run in about two hours.

When the rapids are impassable on account of low water, these rafts and steamboats pass through the canal, and in passing, rafts must be divided into sections, in

order to pass through the locks, and recoupled when the entire raft has passed—making from 8 to 12 lockages at each lock. In this manner it requires the greater part of two days for a raft with its attendant steamboat to pass through the canal.

It is, therefore, of great advantage to a captain of a raft steamboat to know the stage of water at Keokuk when starting from a northern point with his raft in tow. He can calculate the time required for his trips, and make his contract accordingly.

During the winter a peculiar effect is produced in the stage of water at Keokuk by the rapids.

During cold nights anchor ice will form in the rocky bottom and reefs in the rapids to such an extent as to form a partial dam, and on the following morning the river gauge at Keokuk will show as much as a 1½-foot fall. During the morning this underice will loosen, and by noon the gauge will resume the reading of the previous evening.

The country subject to damage from floods lies between Warsaw and Quincy, in Illinois, and south of the mouth of the Des Moines, in Clark County, Mo.; is protected by levees of earth, sodded on the river side, and in some places further protected by willows planted between the base of the levee and the usual bank of the river. These levees will bear a stage of water corresponding to 15 in the iron gauge at Keokuk, and at 18 feet there is continual danger of parts breaking. High water running from the north, caused by spring rains and the melting of snow, is not sufficient of itself to cause a dangerous flood. Should such a rise, however, in passing south, meet a flood coming out of Keokuk River the danger line would probably be reached at Keokuk, though a disastrous flood would hardly result unless it met with a further swell from the Des Moines.

The Des Moines River seems to be the most important factor in all floods which have caused any great amount of damage. It enters the Mississippi 2½ miles south of the station. North of its mouth the banks are high bluffs, with only a narrow margin of land between the bluffs and the Mississippi. South lie large tracts of rich iron bottom.

A flood coming from the Des Moines, even when the Mississippi is at an ordinary stage, will back the Mississippi as much as 6 inches at Keokuk. Should a flood coming from the Des Moines find the Mississippi at or near the danger line it has the same effect, swelling the Mississippi until the Mississippi flood overcomes the Des Moines flood, when the Des Moines is backed up in its time, which is usually when the flood reaches its height, and the greatest damage is done.

Floods occur with the spring rains in April and May, and occasionally, though much rarer, in autumn.

No floods occur from the breaking of ice gorge in the spring. The Mississippi and all tributaries flowing into it north of the station having a southerly course, milder weather beginning at the southern extremity of the ice, the ice moves out in divisions, beginning south, other divisions thawing and moving out from above them at intervals of days.

At Keokuk the action of the swift current on the rapids will back up the ice while the river is yet frozen from below, which brings down a vast body of water, raising the river from 6 to 8 feet in a few hours. The force of the body of water coming down breaks up the ice below, and the river falls as quickly as it can, without doing any damage.

KNOXVILLE, TENN.

[From Report of the Chief of Engineers, United States Army, 1893, Appendix D D.]

Knoxville, Tenn., is on the Tennessee River. The width of the river at low water is 1,050 feet.

The drainage area above it is 8,300 square miles.

The distance to London is 56.4 miles; to Chattanooga, 183.7 miles.

The river gauge is on the west end of the third pier on the north side of Marysville County Bridge over the Tennessee River at foot of Gay street. The gauge extends from zero to 30 feet; average depth of water below zero of gauge, about 1.5 feet.

The bench mark is the bottom edge of a hole drilled in the stone of second course above the ground on the pier immediately behind the gauge. The bench mark is 8.1 feet above the zero of the gauge. The zero of the gauge is 806.6 feet above sea level. The danger line is at 29 feet.

The extreme high water of 1875 and 1876 was 39 feet on the gauge. The extreme low water of 1871 and 1884 was at the zero of the gauge.

The Tennessee River is formed by the junction of the Holston and French Broad rivers, about 4½ miles above Knoxville, Tenn. It flows southwest 51 miles to the mouth of the Little Tennessee River, its first considerable tributary, receiving in that distance only one tributary (other than creeks), the Little Tennessee River.

From the Little Tennessee River it flows west-northwest to the mouth of the Clinch River, the second large tributary, 84 miles from head, and then turning to the left flows south-southwest to Chattanooga, receiving, 150 miles from head, from the southeast, the Hiwassee River. The total length above Chattanooga is 188 miles.

All these streams that form the Tennessee are similar in kind and not very different in size. They rise in the mountains of Virginia and North Carolina and flow down over the rocky, winding beds to their mouths. They are, except the Holston, navigable at ordinary stages for some distance above their mouths, and the French Broad and Hiwassee have regular steamboat service.

The following are results obtained by Col. D. L. Sublett, assistant engineer, at Chattanooga:

Date.	Stage of water.	Discharge.
	<i>Feet.</i>	<i>Cubic feet.</i>
November 13, 1891	3.0	17,550
April 11, 1892	30.0	222,650
Calculated high water of 1897	57.5	740,350
Calculated low water		8,000 to 9,000

LITTLE ROCK, ARK.

By Mr. T. H. CLARK, *Local Forecast Official.*

In discussing the flood stages of the Arkansas River at Little Rock, there are but three stations from which to deduce results—Fort Smith, Dardanelle, and Little Rock. The distance from Fort Smith to Dardanelle is 95 miles, and from that point to Little Rock, 80 miles.

The chief tributaries on the north side of the river, east of Fort Smith, are Mulberry River, Pine Creek, Illinois Bayou, Point Remove Creek, and Cadron Creek; on the south side, Poteau River, which empties into the Arkansas River, at the west side of Fort Smith, Petite Jean Creek, Fourche La Pave River, and Maumelle Creek.

The streams on the north side of the river are generally mountain streams which fill and run out very rapidly; on the south side of the river the tributaries run through a more level country, and consequently remain at a high stage for a longer period.

In forecasting flood stages, the main features to be observed are as follows: The stage at Fort Smith, the volume of water in the river west of Fort Smith, the rainfall between Fort Smith and Little Rock, the length of time it takes for the tributary streams to empty themselves, the amount of water absorbed by sand bars, and the amount that backs up rivers and creeks and overflows the low lands adjacent to the river at a stage very near the danger line.

From a study of the high-water stages which have occurred from 1890 to the present time, great differences are noted in the rise at Fort Smith as compared with that

at Little Rock. In March, 1890, the rise at Little Rock was 89 per cent of that at Fort Smith; in April of the same year it was 103 per cent; in May, 1892, it was 48 per cent, and in June of the same year, 61 per cent; in April and May, 1893, it was 76 per cent, and in March, 1894, 104 per cent. From the above it will be seen that there is a range of 56 per cent between the greatest and least of the comparisons made, but when we eliminate the percentages in 1890 and 1894, on which dates the stages at Fort Smith were below the danger line, we find a range of but 28 per cent between the highest and lowest.

On an examination of the fluctuations between the rise at Fort Smith and that at Little Rock, it is noticed that the higher the stage at Fort Smith the less the relative rise between the two stations, and this is more noticeable when the river is below the danger line at Fort Smith. There is one exception to this rule in the data under discussion—that of April and May, 1893—but this was caused by the unusually heavy rainfall between Fort Smith and Little Rock during the last days of April and 1st of May.

The following tabulated statement will illustrate the point more fully:

Date.	Maximum stage.		Rise at Fort Smith that reached Little Rock.
	Fort Smith.	Little Rock.	
	<i>Feet.</i>	<i>Feet.</i>	<i>Per cent.</i>
Below danger line:			
March, 1894.....	17.3	22.6	104
April, 1890.....	20.9	24.2	103
March, 1890.....	21.0	22.3	89
Above danger line:			
June, 1892.....	25.9	25.8	61
April and May, 1893.....	26.8	25.2	76
May, 1892.....	30.9	27.9	48

This great falling off in the relative rise of the river between Fort Smith and Little Rock when the stage is above the danger line at Fort Smith, is not so much due to the increased width of the river at a high stage as it is to the overflows and water backing up the rivers and creeks.

At a stage of 22 feet at Fort Smith and 23 feet at Little Rock the river begins to flood low lands between Van Buren and Mulberry, in the vicinity of Dardanelle and Oppelo, and from the mouth of the Fourche La Fave River to just west of Little Rock. Back water ascends the Fourche La Fave and Maumelle to a considerable distance. As shown by the stages at Fort Smith, Dardanelle, and Little Rock, the greatest escape of water from the river is between Dardanelle and Little Rock.

The crest of a freshet wave takes about two days to reach Little Rock from Fort Smith; the average is slightly less than that, depending on the amount of rainfall between the two stations—the less the rainfall the slower the movement of the wave.

At ordinary stages and up to about 21 feet at Fort Smith, Little Rock will receive about an equal rise with Fort Smith; from 21 to 26 feet at Fort Smith, Little Rock will receive about 70 per cent of the total rise at Fort Smith, and from 26 to 30 feet at Fort Smith, Little Rock will receive about 50 per cent of the total rise at Fort Smith.

These rules must be modified somewhat according to the rainfall between the two stations; if general and heavy, the percentage of rise must be increased, and if light or local, reduced. There must also be a great reduction in the above percentages when the stage at Fort Smith exceeds 30 feet and that at Little Rock 28 feet.

Nothing is known of river stages from Little Rock to the mouth of the river, but at 22 feet at Little Rock the river begins to overflow from about 12 miles east of Little Rock to the mouth of the river.

MEMPHIS, TENN.

By Mr. WM. M. WILSON, *Observer*.THE EFFECT OF THE ST. FRANCIS BASIN ON FLOOD HEIGHTS AT MEMPHIS AND
HELENA.

The St. Francis River has its origin in the low land and swamps lying on the west bank of the Mississippi, about 40 miles north of Cairo. Its course is southward through northeastern Arkansas, and empties into the Mississippi about 12 miles north of Helena. This river drains a portion of southeastern Missouri and nearly the whole of northeastern Arkansas. The drainage area of this stream and its tributaries is comparatively small, about 8,000 square miles, and, as would be expected from this limited area, the effect on the Mississippi at medium and low water stages is nearly inappreciable; but with the great floods which yearly flow down the valleys of the upper water courses, this river assumes an importance by no means commensurate with its apparent insignificance.

The west bank of the Mississippi River from Commerce, Mo., some 40 miles north of Cairo, to the mouth of the St. Francis, is very low, and at a stage of about 42 feet on the gauge at Cairo the water begins to pass through numerous channels, and rapidly fills the basin of the St. Francis.

There has never been any accurate measurement made of the discharge into this basin at the different heights above the flood plane at Cairo, and the estimates made by various engineers show so wide a difference that they are practically valueless.

The basin of the St. Francis is filled with thick undergrowth, canebrakes, and forests, which increase the friction and materially retard the current of that stream; so that the flood wave in the St. Francis is several days behind that of the Mississippi. Again, the basin, being limited in capacity, must of necessity fill before the flood wave can begin its progress, which is another factor in delaying the effect of the wave in that stream.

In order to show the effect of the St. Francis Basin on the flood wave at Memphis, investigation has been made of the relation existing between the gauges at Cairo and Memphis for crest waves of 10, 15, 20, 25, 30, 35, 40, 45, and 50 feet. For this comparison a mean of all waves passing Cairo within 1 foot of the above stages, and the mean of the crest of the same waves when reaching Memphis has been obtained. These data are as follows:

Cairo.	Memphis.	Difference.	Increase of ratio.
9.9	6.3	3.6	-----
15.2	10.1	5.1	1.5
20.1	14.3	5.8	0.7
25.0	19.0	6.0	0.2
30.2	23.0	7.2	1.2
35.0	26.7	8.3	1.1
39.9	30.6	9.3	1.0
45.2	33.7	11.5	2.2
50.2	35.0	15.2	3.7

The above means can be plotted as a straight line up to the 40-foot stage at Cairo (see chart 1), which shows that a uniform relation exists at all stages below the flood line. When, however, a stage of 40 feet is reached at Cairo, the previously existing relation entirely disappears, and instead of a straight line, we have a curve which apparently sustains a very indefinite relation to the Cairo gauge. It is to be noted in the above table that the greatest increase in the ratio between the gauges below 40 feet is 1.5 feet, while the mean increase up to the 40-foot stage is 1 foot. From 40 to 45 feet the actual increase of ratio becomes 2.2 feet, which clearly shows that there is a decided falling off in the Memphis reading as compared with the stage to be expected from the Cairo gauge. If we apply the average increase of ratio existing below 40 feet and which is bound to be 1 foot to the 45-foot stage at Cairo, the

Memphis gauge would read 34.9 feet instead of 33.7 feet. It is further noted that the increase of ratio from 45 to 50 feet is 3.7 feet. By applying the mean ratio of increase to the 45 and 50 foot stages, the reading at Memphis for a stage of 50 feet at Cairo becomes 38.9 feet instead of 35 feet. These values charted strengthens the curve and makes the line thus obtained coincide with the line of mean relative readings below 40 feet. The difference between the height thus found, 38.9 feet, and the actual reading obtained from a 50-foot rise at Cairo is considered to approximate very closely the effect of the St. Francis Basin in reducing flood heights at Memphis.

If the St. Francis Basin should be leveed and the relation which has been found to exist between the Memphis and Cairo gauges below 40 feet should be continuous above that plane, the river at Memphis for a 50-foot stage at Cairo would rise about 4 feet above the present maximum flood plane.

In order to show the effect of a flood wave from the St. Francis on the Mississippi River when returning to that stream the mean gauge relation between Memphis and Helena for flood waves which passed Cairo at 10, 15, 20, 25 feet, etc., has been obtained. These relations can also be platted as a straight line up to a stage which corresponds to 40 feet at Cairo, when, as before, the relation disappears. Instead, however, of the Helena gauge showing a lower relative reading than Memphis, as is the case with Memphis when compared with the Cairo gauge, exactly the reverse is found, the curve indicating a greater relative height at Helena than at Memphis.

By a cursory examination of the Memphis and Helena hydrograph for any flood year it will be plainly indicated that there is some powerful factor operating at Helena not to be accounted for by the Memphis chart. The year 1893 affords a notable example of this fact. (See chart 11.) The crest of the flood wave passed Memphis on May 15 to 17, 1893, at a maximum stage of 35.2 feet. The rise for five days preceeding the 15th was 0.3 foot. At Helena the crest passed on May 25, ten days after the maximum height was reached at Memphis, at a stage of 47.9 feet, and the rise for the five days preceeding was 2.1 feet. Every flood that has remained above the 40-foot stage at Cairo for any considerable time, when charted, exhibits this same abrupt curve. It is also noted that the time of the occurrence of the crest at Helena is several days later than would be the case did the Helena gauge depend entirely on water which had passed Memphis.

If we take into consideration the stage at Wittsburg, on the St. Francis River, this apparent discrepancy in readings is easily explained, and it becomes evident that the flood height at Helena depends more on the stage at Wittsburg than the height to which the wave attains at Memphis.

Notwithstanding the energy expended in filling the basin and the force lost in overcoming the friction caused by undergrowth along its bed, the St. Francis River still retains sufficient "head" to force the reading at Helena more than 2 feet higher than the Memphis stage would indicate.

The effect of the St. Francis Basin upon flood heights at Memphis and Helena may be summed up as follows:

1. This basin acts as a reservoir, receiving a large portion of the water which would otherwise flow down the Mississippi River, and thus lowering the flood crest at Memphis about 4 feet below the point indicated by the rise at Cairo did the same relation exist above 40 feet that is found below that line.

2. The water is again returned to the Mississippi 12 miles above Helena, raising the flood plane at that point about 3 feet higher than would be expected from the maximum stage at Memphis.

3. The filling of the St. Francis Basin and the resistance caused by undergrowth and forests retard the flood wave in that stream so that its effect is felt at Helena after the crest wave in the Mississippi has passed that point.

4. The leveeing of the St. Francis Basin would be to cause the flood wave to pass down the Mississippi River from Cairo to Helena as a whole, both as to volume and time: and it is probable that the gauge relations existing between Memphis and

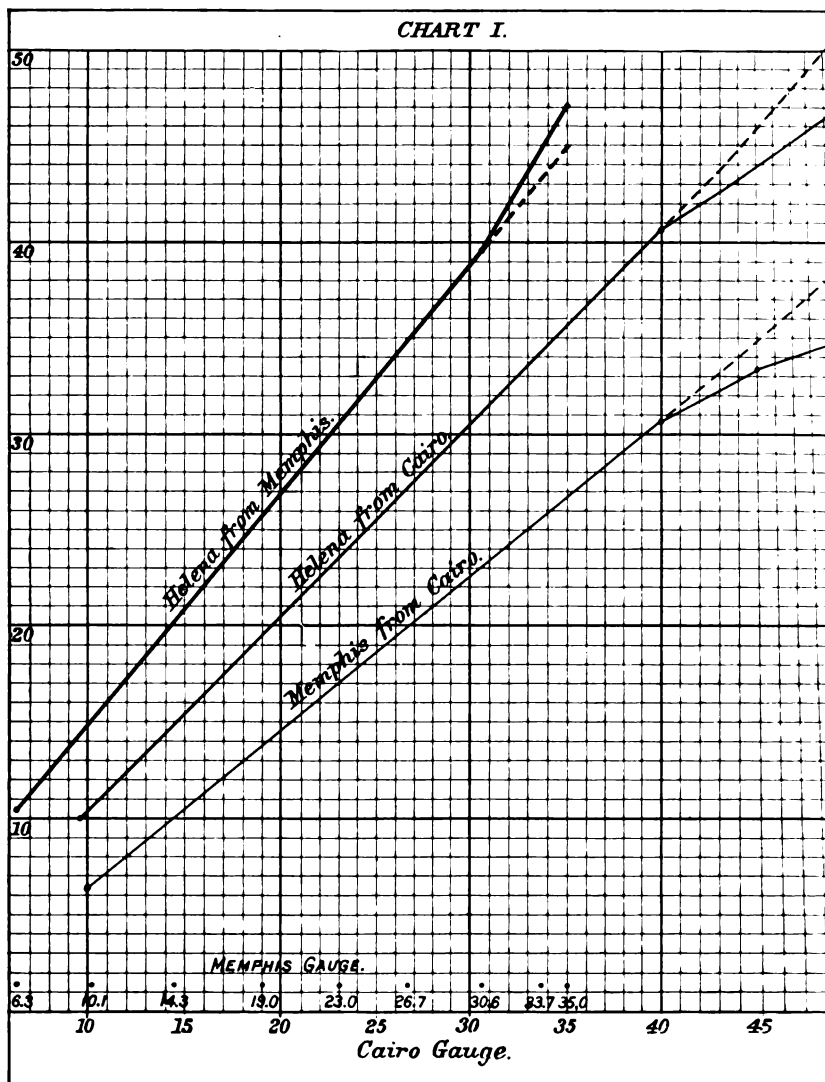
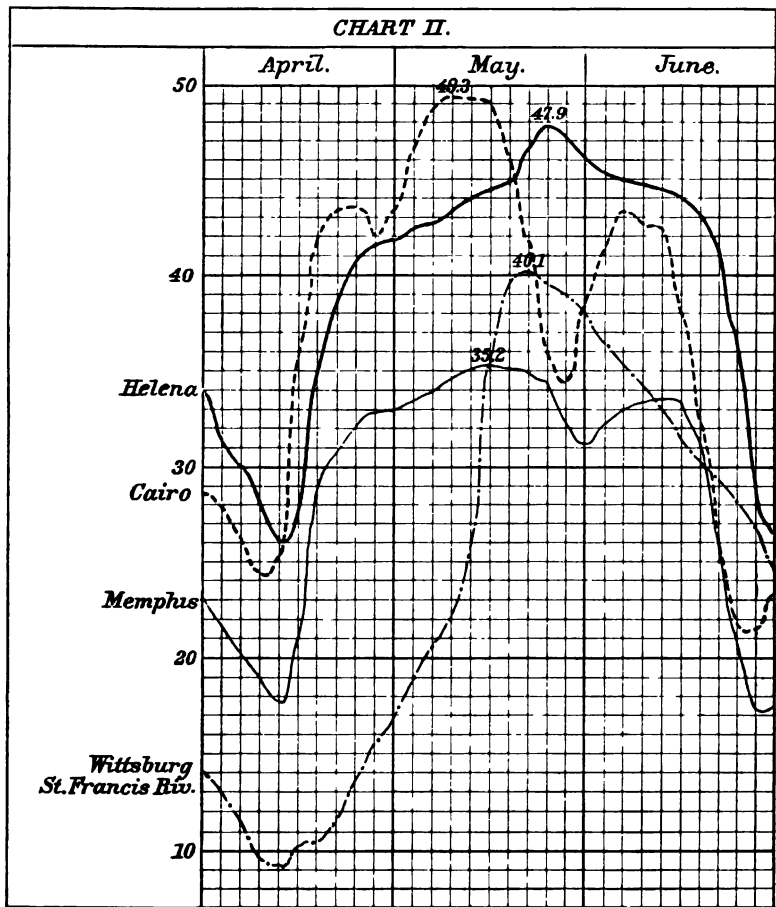


FIG. 2.—GAUGE RELATIONS BETWEEN CAIRO AND



RO AND MEMPHIS, AND MEMPHIS AND HELENA HYDROGRAPHS.

Cairo and Helena and Cairo below the flood line would tend to be sustained for waves above that height, and the guage reading at Memphis and Helena would approximate the relative height to be expected from a given rise at Cairo.

MONTGOMERY, ALA.

By Mr. F. P. CHAFFER, *Local Forecast Official.*

These rivers may be divided into two systems, the northeastern and northwestern. The northeastern system is composed of the Alabama, formed by the junction of the Coosa and Tallapoosa, the Coosa being formed by the junction of the Oostanaula and Etowah rivers of Georgia. This system, down to where the Alabama empties into the Mobile River, drains an area of about 22,000 square miles.

Above Rome the Oostanaula and Coosawattee rivers are navigable at moderate stages for a distance of 105 miles, and the drainage into these rivers is rapid, as the watersheds are quite abrupt and the soil is mostly of an impermeable character. From Rome to Greensport, Ala., a distance of 162 miles, the Coosa has stable banks and bottom and a normal width of from 300 to 500 feet. From Greensport to Wetumpka, a distance of 142 miles, the character of the river changes; it flows through a rocky country with a succession of shoals and deep pools, varying in length from 1 to 8 miles, with occasional rocky obstructions, which frequently rise above the surface of the water, the water varying in depth from a few inches to several feet. The total fall of the low-water surface from Greensport to Wetumpka is 367 feet. The average low-water width of the river is from 600 to 800 feet. At "The Narrows," about midway of this stretch, it contracts to 100 feet, with a depth of over 85 feet, while the greatest width is 3,700 feet at Butting Ram Shoals, about 38 miles above Wetumpka, where the water is very much dispersed and the river bed an intricate mass of rocks, reefs, and islands.

Observations at Wetumpka, in the fall of 1889, showed a low-water discharge of 5,796 cubic feet per second, which is almost exactly the same as reported for the low-water discharge of the Mississippi River at St. Paul.

The width of the upper Alabama River at low water varies from 500 to 600 feet, and the lower river from 700 to 800 feet, the average slope of the river being about 4 inches to the mile (f). The drainage into this entire system is very abrupt from the west; the divides between the Tombigbee and the Alabama. The watershed from the eastward, while quite abrupt in the northeast portion of the system, flattens out very decidedly in the central and southern portions.

Owing to the impermeable nature of the ground and the incline of the watershed in the northern section, 1 inch of rain in that section would have as much effect upon the middle and lower rivers as would 2 inches of rainfall in same time in the middle section where the ground is more permeable, or 6 inches in same time in the southern section, where the ground is quite absorbent.

Observations of river stages covering the period from 1891 to 1894, inclusive, have been charted at this office, from which the following is deduced:

At moderate stages, less than 25 feet: The rises at Rome, Ga., are felt at Montgomery in about 2 days, with an average rise of 7.3 feet over the Rome stages. From Montgomery to Selma, in 1.6 days, with an average rise of 2.7 feet over the Montgomery stage. Selma to Claiborne, in 2.1 days, but owing to the width of the river and low banks below that point, the rise averages 1.9 less than the rise at Selma.

Stages of 25 feet and over: Rome to Montgomery in 1.7 days, with a rise of 8.9 feet over the Rome stage. Montgomery to Selma, 1.8 days, with a rise of 2.5 feet over the Montgomery stage. Selma to Claiborne, 4.4 days, with the average rise 6.7 feet less than the Selma stage.

It is noticed that the rise at Montgomery depends very much upon the combined inflow from the Tallapoosa and Coosa rivers; fortunately for this section, freshets that occur in the Tallapoosa (as indicated by the Indian meaning the words "Swift Water"), as a rule run into the Alabama and flow off before the full effect of the inflow from the Coosa is felt.

The northwestern, or Tombigbee system, composed of the lower Tombigbee, which is formed by the junction of the upper Tombigbee and the Black Warrior rivers, drains the northeastern portion of Mississippi and nearly all of Alabama west of a line drawn diagonally from southwest to northeast, across the State; in fact, the dividing ridge of the watershed between the two great river systems of this State inclines the same as the general direction of the Appalachian chain of mountains.

As of the northeastern rivers, the same may be said of the watersheds of the upper Tombigbee and the Black Warrior rivers. They are quite abrupt and are composed mostly of rapids above Columbus and Tuscaloosa, are confined to high banks, and the currents are quite swift. The ground surface of the drainage area is divided into the same belts and has very nearly the same characteristics as that of the Alabama and tributaries and is mostly affected by heavy rains in northwestern Alabama and northeastern Mississippi.

The distance from the head waters of the Tombigbee to where that river empties into the Mobile River is about 390 miles. This system drains about 200 square miles.

Average water stages in the Upper Tombigbee reach Demopolis from Columbus, Miss., in 1.8 days, while from Cordova to Tuscaloosa the river distance is nineteen hours and from Tuscaloosa to Demopolis about one day.

At high-water stages it takes a rise at Columbus 1.3 days to travel to Demopolis, with an average rise of 8.4 feet above the Columbus rise.

From Cordova to Tuscaloosa the average time is 0.7 of a day with an average rise of 14.3 feet over the Cordova rise.

Tuscaloosa to Demopolis 3.1 days, with an average rise of 9.2 feet over the Tuscaloosa rise.

It is noticed, however, that in many cases with a freshet coming down the Black Warrior and the upper Tombigbee, the waters from the latter will back up into the Black Warrior and increase the stage at Tuscaloosa, which backwater, after the pressure has been relieved below, will cause a secondary rise at Demopolis about four days later.

Owing to the width of the river and the lowlands below the junction of the Tombigbee and the Alabama, the backwater from either of these rivers has no perceptible effect upon the other.

It is almost impossible to formulate any empirical rule as to the exact effect of rainfalls, reported each twenty-four hours, upon the stage of the rivers of this section.

The intensity and frequency of the rain, as well as the condition of the ground in the watershed, must be considered. For instance, after a prolonged drought, a sudden and heavy rain upon the ground which has been baked to a hard crust will nearly all flow off into the streams, while the same amount falling slowly would be absorbed by the dry earth and go toward replenishing dry springs or be taken up by famishing vegetation and not be felt in the larger rivers for many days.

It is found that the dangerously high waters which have occurred in this section have been during the months from January to May, inclusive, and that the extremely high waters have occurred in January and the latter part of March and during the month of April.

The rains which cause the highest rivers in this section are sudden and excessive, or heavy and prolonged winter and spring rains over northeastern Mississippi, northern Alabama, and northwestern Georgia.

Owing to the extended low-water period usual in these rivers—from June to November, inclusive—regular observations at all river and rainfall stations of this section were discontinued during these months, and special observations telegraphed only when the stages of the rivers or heavy rainfalls made such observations necessary to warn the interests affected.

It is learned from reliable sources that great floods occurred in the rivers of this section in the spring of 1833, and that during the summer months of 1839 (six years

later), the water was so low as to permit walking across many portions of the Alabama River. The low waters of the fall months of 1894, said to be lower than at any time since 1839, seems to indicate a period of fifty-five years between extreme low waters.

NASHVILLE, TENN.

By Mr. J. B. MARBURY, *Local Forecast Official.*

The Cumberland River rises in the mountains of southeastern Kentucky and flows in semicircular course through the upper and central portions of the State of Tennessee. Its course is extremely crooked for the first 200 miles from its source, after which it is less serpentine. For about 200 miles it passes through a very rough and mountainous country which forms sheds whose drainage is either directly into the Cumberland or brought to it by some of its many tributaries. The upper portion of the river is subject to sudden and decided changes, due both to the topography of the country on either side and to the narrowness of the stream. Near Nashville the river widens and the country becomes less mountainous and rugged, affording less drainage and as a consequence the changes, while still great, are less than at and above Burnside.

The more important of the tributaries of the Cumberland are the Laurel and Rockcastle rivers, 10 and 20 miles above Burnside. These rivers drain a large area of the mountainous country, thus causing sudden and decided rises at Burnside with comparatively small rainfall in that vicinity. At Burnside, it is narrow, not over 100 feet wide at low water. On either side of the river from that point to about 100 miles lower down are high and steep banks. From Burnside the river widens gradually to about 400 feet at Carthage at low water and about 700 feet at Nashville. From Nashville to its mouth its width increases.

At Celina, a point about halfway between Carthage and Burnside, the Cumberland receives the water drained from a large section of country by the Obey River. Caney Fork, another important tributary, enters the Cumberland with water drained from a large area just above Carthage. The last tributary of importance reached before arriving at Nashville is the Stone River, which reaches the Cumberland about 10 miles above Nashville.

Changes noted at Burnside generally affect the river at Nashville in from forty-eight to fifty-six hours and are usually modified decidedly by the time this point is reached. A rise or fall at Carthage is noticed here in about twenty-four to thirty-six hours.

The higher the river the less effect a change at the two upper stations have on the river at Nashville. At a 35-foot stage at Nashville, 10 feet change at Burnside will change the readings at Nashville very little unless there have been general rains along the entire course above the last-named point. This fact is due to the widening of river banks and the overflows at various points above this city.

During very high water one peculiarity is noticed here. With the water at or above the 45-foot point it will continue to rise at Nashville for several days after it has fallen at both Carthage and Burnside. Upon investigation it is found that this is due to the fact that the approaches to the two bridges at this point form dams and only allow the water to escape between the piers of the bridge; there is also a third bridge 2 miles below this city whose approaches form a dam fully a mile wide. The combined influence of these forces, I think, is the cause of the rise on the gauge at Nashville mentioned above.

NEW ORLEANS, LA.

By Mr. R. E. KEEKAM, *Local Forecast Official.*

A wave of water will occupy about five days in traversing the 366 miles between Vicksburg and New Orleans, and the rate of travel is faster just below Vicksburg, or between Vicksburg and Bayou Sara, than between Bayou Sara and New Orleans. As a general thing it is found that one-third of the Vicksburg rise will equal the New Orleans rise, and that the Bayou Sara rise is somewhere between one-half and

one-third the amount of the Vicksburg rise; or, a 35-foot Vicksburg rise will give about 25 feet more water at Bayou Sara and from 10 to 11 feet more at New Orleans. The exact proportion of the flow of Mississippi River water down the Atchafalaya is not yet determined.

Having withstood a stage of 15 feet at New Orleans upon several occasions during late years, it is evident that great improvement has been made in the levee system along the Lower Mississippi; and in view of such facts, the danger line of 13 feet is not, in reality, a danger line any longer. It is only when a stage exceeding 15 feet is anticipated that the levees are closely watched and strengthened wherever necessary, and it is therefore recommended that a new danger line of 15 feet be used for New Orleans. With a stage of 17 feet on the New Orleans gauge the water from the river will commence to flow over the levees, rendering it necessary to erect temporary levees along the city front. Improvements are constantly being made in the levee system of the State, and back or protection levees are placed at many points where, owing to a curving river, the danger of breakage is greater. While scarcely within the province of the Weather Bureau to suggest, yet the disasters of the all-levee system of past years to the agricultural interests render the subject of levees and outlets against all levees of particular interest. The fact remains that our extreme high water of late years in the Lower Mississippi Valley was only a part of that which might have come; that this lower valley has not as yet felt the full effects of the combination of waters from the several central and upper valleys with heavy spring rains; and that it is not unlikely that at some time or other that this condition must be met. A study of the effects of combinations of high waters on the Lower Mississippi Valley would be of great value.

There are so many minor tributaries of the Ouachita River in northeast Louisiana to drain that section that crevasse water from Arkansas is feared by the planters in our northeastern parishes, or breaks in the levees in East Carroll, Madison, Tensas, or Concordia parishes of Louisiana. The marked fluctuations in the Ouachita at Camden are never felt at Monroe, since between Camden and Monroe there is a large tract of country that, when the stage at Monroe passes the 20-foot mark, is overflowed, acting as a reservoir for the flood waters from the upper Ouachita and keeping the stage at Monroe at a more gradual rise or fall. It will be noticed by a reference to chartings of the Ouachita that, whenever the stage at Monroe falls below 20 feet, with a falling river above, the decline is quite rapid to low water. On an average the river at Monroe will show a rise two-thirds as great as at Camden, and within about four days thereafter, if the river at Camden rises some 20 to 30 feet within a week and from a low stage. The rate of travel of a freshet wave between the two points is about 60 miles per day, as near as can be determined.

An approximate rule to follow in forecasting the rises at Shreveport, Coushatta, and Alexandria, on the Red River, is that Shreveport will have from one-half to two-thirds of the rise that occurred at Fulton, Ark., while Fulton will be about one-fifth less than Arthur City, Tex. Coushatta will have about four-fifths of Shreveport's rise, and Alexandria usually has a rise that averages half again as much as at Coushatta. The time consumed to travel the 683 miles between Arthur City and Alexandria is about ten days, and about four days from Alexandria to New Orleans.

PARKERSBURG, W. VA.

By Mr. H. W. RICHARDSON, *Observer*.

The entire State is either mountainous or hilly. The Alleghany and Shenandoah mountains bisect northeast and southwest the eastern arm of the State, the Alleghanies continuing southwest and dividing the State from Virginia to including a portion of the southern border. Parallel to the Alleghanies and running southwest from Pocahontas County is a ridge composed of the Greenbrier Mountains at the northeastern extremity, then follow the Great Flat Top range, finally culminating in what is termed the Dividing Ridge, which follows the entire southern border of McDowell County, W. Va., and the northern borders of Tazewell and Buchanan

counties in Virginia. A broad and rather undulating valley covers the intervening territory between the chain of mountains just described and the Alleghanies. The general trend of both chains of mountain systems northeast and southwest through the eastern and southern portions of the State forms the watershed, and the entire district north and west is drained by the Potomac. All the streams of the State have a rapid fall, and consequently run out quickly after flood stage; the rise from normal to flood stage being equally as sudden. The area drained by the Ohio and tributaries at and above Parkersburg is about 34,600 square miles. The difference in altitude between Parkersburg and Oil City, Pa., is about 422 feet; between here and Pittsburg the fall is more gradual, slightly over 130 feet. Parkersburg is distant from the former place nearly 300 miles and from Pittsburg about 182 by river. The Ohio River is increased by the Muskingum at Marietta (12 miles above Parkersburg), by the Little Kanawha at Parkersburg, the Great Kanawha at Point Pleasant (82 miles below), and the Big Sandy at Catlettsburg, Ky. (52 miles below Point Pleasant). The highest water known at Parkersburg was 55 feet on February 9, 1884; the lowest was 0.3 foot on the 10th and 11th of September, 1894; in fact, during the greater portion of July, August, September, and October, 1884, it was unusually low; on forty-five days of the four months mentioned the river reached a stage as low and lower than that of October 30, 1879, 0.66 foot. Navigation is generally open on most of the rivers except in July and August and a part of September, when few if any boats are running on account of low water. Trouble is experienced in the winter months of course on account of ice, but it is the exception rather than the rule that a complete tie-up on this account occurs. The months most favorable for navigation are March, April, May, and June; October, November, and December are also usually favorable, although occasionally there is an exception when during October and November navigation is suspended because of low water. In the section covered by the Ohio and tributaries in West Virginia the average annual precipitation varies from 30 to 35 inches in Ohio, Marshall, Wetzel, Mason, Putnam, and Cabell counties; in the counties of Monongalia, Preston, Tucker, Grant, and Mineral from 40 to 50 inches fall annually; in the intervening districts not mentioned, but tributary and including watershed on eastern and southern borders, the annual precipitation is anywhere from 35 to 45 inches. In the territory drained by the Potomac it varies from 45 to 50 inches in the counties in the region of the Alleghanies and bordering on Maryland to 30 to 35 inches in the extreme arm of the State. The annual snowfall in West Virginia averages in depth about 3 feet over the region covered by the Ohio Valley, the fall then increases gradually to about 6 feet over the territory drained by the Monongahela and the upper Potomac; in the extreme eastern portion of the State drained by the Potomac the average snowfall is about 3 feet. It is very seldom that the Ohio and tributaries in this section are completely closed up by ice. When this occurs, much danger is apprehended on account of the ice gorging and the final break-up. If the snow and ice thaw gradually, no serious consequences ensue, but if the break-up is caused and is accompanied by continual warm weather and copious rains the results are apt to be disastrous. The months most favorable for floods are January and February. Freshets occasionally occur in March, April, May, and September, and a good rise is almost always confidently looked for in June. An examination of the records discloses the fact that in the majority of instances Pittsburg is the main index point as regards an expected flood stage at Parkersburg. Whatever the flood stage at Pittsburg may be, the flood stage at Parkersburg will be about 12 feet higher nearly two days later, the rate of travel of crest being about 92 miles per day between the two points. Of course the flood stage at Parkersburg might be slightly more or less than indicated by the additional 12 feet more than at Pittsburg, depending altogether upon conditions existing as to the distribution of the rainfall, the amount of snow on the ground in the districts drained, the thickness of ice, if any, in the rivers, and the location and extent of ice gorges. Ice is a specially important feature both as to gorges and displacement when in motion. Careful study of previous records and the consideration, combined with

a fairly accurate knowledge, of the effects of the conditions mentioned in time reduces such calculations to something like a pure mechanical process. Much depends also as to whether the rivers are running out rapidly below Parkersburg; the Great Kanawha and Big Sandy when running full have a tendency to "back" the water in this vicinity. As a rule, the Muskingum and Little Kanawha run out quickly; when these rivers have a "secondary" rise and run out on top of a flood stage in the Ohio, it almost always follows that Marietta and Parkersburg are visited by more than usual flood. A fall at head waters to Pittsburg and below Davis Island Dam is generally followed by a fall at Parkersburg of from two to two and one-half or nearly three days later, other conditions being equal and the Muskingum and Little Kanawha quiet. The "danger line" at Parkersburg is 38 feet, but this is thought to be too high, as at a height of 38 feet many houses in Riverside, an eastern suburb adjoining the Ohio and but recently added to the city, have to be abandoned; at 37 feet several of these houses are half under water. The river gauge is at the junction of the Little Kanawha with the Ohio, is attached to a pier of the Ohio River Railroad Bridge, and extends to a little more than 40 feet above the zero. There is a United States engineer's gauge on the opposite side of the Ohio at Belpre. River information is valued here by almost all classes of citizens. The interests affected are many and varied. Traffic on the Ohio is mostly in coal and merchandise, although a few boats are equipped with passenger facilities more especially. On the Little Kanawha there are all the other interests combined, together with an immense amount of timber in the shape of logs and ties annually brought out. Frequently millions of feet of timber lie in the upper waters of this river awaiting a rise; as a consequence weather forecasts are watched with the keenest interest by those financially concerned. The Little Kanawha is navigable to Creston, 58 miles above Parkersburg. Transportation is effected almost entirely by boat, there being no railroad through.

The river reports received at Parkersburg are as follows: Monongahela, Morgantown; Alleghany, Oil City, Parkers Landing, Pittsburg; Ohio, Davis Island Dam (from Western Union free), Wheeling, Marietta (telephone free), Point Pleasant, Cincinnati, Cairo; Great Kanawha, Hinton and Charleston; Little Kanawha, Creston and Leachtown, daily, free by telephone, and any other points desired. Importance is attached to all these reports, and the river bulletin has been made an especial feature on the daily weather map.

PORTLAND, OREG.

By Mr. B. S. PAGUE, *Local Forecast Official.*

THE COLUMBIA AND TRIBUTARY RIVERS EAST OF THE CASCADES.

The Columbia River, with its tributaries, drains that portion of the United States west of the one hundred and thirteenth meridian and north of latitude 42° except a portion of northwestern Washington and southwest Oregon. The greater portion of the eastern half of British Columbia is also drained by the Columbia and its tributaries. The area drained amounts to upward of 350,000 square miles, or about 225,000,000 acres. The main tributaries of the Columbia are the Willamette in western Oregon, the Snake in Idaho, the Kootenai of Montana and British Columbia, and Lake Pend Oreille in northern Idaho.

Station.	Average annual precipitation.	Average for five months (November to March, inclusive).
Helena.....	14.27	4.46
Spokane.....	20.08	11.04
Walla Walla.....	17.94	10.08
Umatilla.....	9.96	5.67
The Dalles.....	15.57	11.84
Baker.....	14.63	8.10
Boise City.....	14.30	8.07

The above stations cover the country drained and represent very fairly the precipitation to be carried off by the Columbia River. In the second table the average for five months shows approximately the amount of snowfall.

Helena, Mont., lies close to the highest elevation of the Rocky Mountains in that latitude (nearly 47° N.). There the precipitation is partially due to cyclonic areas moving southward on the east side of the Rockies. About 32 per cent of it is in the form of snow, which would make about 4 feet of snow per annum. This represents approximately the amount of snow in the mountains of western Montana to be melted by the warm weather of spring and early summer and emptied into the streams.

Spokane, in northeastern Washington, has the highest precipitation of the stations given above. This is due to its proximity to the western slope of the mountains and the topographical features surrounding it. While the precipitation given for the months likely to have snowfall is about 11.04 inches, it must not be surmised that there is that much snowfall at that point. Spokane has an average of approximately 6 feet of snowfall per annum, and this fairly represents the amount of snowfall in the mountains of northeastern Washington, northern Idaho, and southwestern British Columbia that will be melted in the springtime.

Walla Walla, in the southeastern portion of Washington, represents the great basin of the Columbia with 17.94 inches of precipitation, of which 10.08 inches occur during the months when snow is probable. Owing to peculiar climatic conditions, January is the only month having a mean temperature below the freezing point, viz, 30.6° . January and February are the only months with a mean minimum temperature below 32° . The lowest mean maximum occurs in January, viz, 36.3° ; hence it is seen that in the immediate Columbia River basin there is but little chance for any material amount of snowfall to influence the river during flood periods.

Umatilla, in Oregon, and to the west of Walla Walla, has an annual precipitation of 9.96 inches, of which there is a possibility of 5.67 inches in the form of snow. Its climatic conditions being quite similar to those of Walla Walla, there is small snowfall to influence the river. Umatilla represents the eastern slope of the Cascade Mountains, while Walla Walla the eastern side, or more nearly the center, of the valley, between the eastern slope of the Cascades and the western slope of the Rocky Mountains.

The Dalles, Oreg., lies on the immediate eastern side of the Cascades, about 45 miles from their crest (latitude $45^{\circ} 30'$ N.). Here is found an annual precipitation of 15.57 inches, with about 11.34 inches thereof during probable snowfall periods. The climatic conditions here do not differ much from those of Walla Walla, yet the 11.34 inches of snow can be approximately used as the amount of precipitation that occurs on the eastern side of the Cascades for a distance of 45 miles from the summit.

Baker City, Oreg., and Boise City, Idaho, represent very fairly the amount of precipitation that occurs over Oregon, east of the Blue Mountains and over the whole of Idaho.

These stations show about 8 inches of water from probable snowfall; not over one-half this amount is subject to use during the time of probable flood periods, due to the frequent melting of snow during the winter time under the influence of the "Chinook winds." The "Chinook winds" affect the whole country now being discussed, and by frequently melting the snow during the winter months cause the water to run off and reduce the supply for flood purposes.

FLOODS AND THEIR CAUSES.

The Columbia River flows for about 400 miles before it strikes the international boundary line in northeastern Washington, thence 769 miles to the Pacific Ocean. The Columbia enters the United States at an elevation of about 1,305 feet. The Snake River has its source in the vicinity of the Yellowstone National Park, in Wyoming, and is some 900 miles long to Pasco, Wash., where it empties into the Colum-

bia. The elevation of the Snake along its course to where it strikes the boundary line of Oregon is over 2,000 feet, from which point to the Columbia River it falls rapidly. Pasco, Wash., at the mouth of the Snake, has an elevation of 410 feet. From Pasco to the mouth of the Willamette (Portland) the distance is 240 miles, and there is a fall of 400 feet.

The results of the survey of the Columbia River, made about three years ago by the United States Engineer Corps, show at one portion of the river south of the international boundary line, where the observations were made to determine the volume of flow, that at a low stage of water the flow was 50,000 cubic feet per second, and at a high stage of water 300,000 cubic feet per second, the difference between high and low water at that point being 40 feet. The flow of the Snake River at an average height may not exceed by more than one-half the flow of the Columbia at the point observed. The mountains furnishing the snow for the river's supply are the Cascades, Colville Mountains, Chelan range, Cœur d'Alene and Kootenai mountains, Selkirk, and Purcell ranges, Salmon River Mountains, Blackfoot, Cariboo, Bannock, Port Neuf, Snake River, and Blue mountains. The last named in Oregon, the preceding six in Idaho, the others in Montana, British Columbia, and Washington.

The accumulated snow of winter gives away to the increasing heat of summer, and from this cause high water and sometimes floods result. The best example of flood causes will be found in the high water of 1894, when the Columbia River was higher than ever before known. The amount of precipitation during the winter of 1893-94 was about normal, but the temperature was slightly below the average, which permitted of a great accumulation of snow, which was later rapidly melted during a warm period in the latter part of May.

The flood was the more severe below the mouth of the Snake on account of the snow along the upper Columbia and along the Snake melting at one and the same time. So far as precipitation is concerned, conditions favorable for the occurrence of floods in the Columbia obtain every year; but the floods depend entirely upon the temperature conditions. An early spring or a slowly approaching spring will cause a gradual melting of the snow and no especially high water will result; but a late spring, with a sudden period of warm weather, will surely produce flood conditions.

The following table shows the date of the highest water at Portland, Oreg. (on the Willamette River), each year since 1880, due to the rise in the Columbia River and consequent backwater in the Willamette:

Year.	Highest.	Date.	Year.	Highest.	Date.
	<i>Feet.</i>			<i>Feet.</i>	
1880	25.4	June 30 and July 12.	1888	18.2	June 18.
1881	19.7	June 16.	1889	10.0	May 21.
1882	23.2	June 15.	1890	20.1	May 20.
1883	17.9	Do.	1891	14.1	June 7.
1884	20.2	Do.	1892	19.3	June 24.
1885	14.5	June 23.	1893	21.0	May 22.
1886	20.0	June 9.	1894	22.0	June 15.
1887	25.7	June 21.		33.0	June 7.

The above shows that the Columbia River floods occur from May 15 to July 15, with a great number of them before June 20. As noted before, the rise in the river depends upon the rapidity of melting of the snow, and this is due to the temperature. The flood probabilities are determined from the temperature conditions that prevail from about May 15 to June 15.

HISTORY OF THE COLUMBIA RIVER SERVICE.

River gauge readings have been made at Cascade Locks, Oreg., by the United States Engineer Corps since 1880 and are still being carefully made at this date, copies of the records being at the disposal of this Bureau. Readings of the river

gauge have been taken for part of each year at The Dalles, Oreg., since 1890. At Umatilla, Oreg., readings were taken from March, 1878, to March, 1887; partial readings only from 1883 to 1887. In 1890 and 1891, readings were taken only during probable flood periods, and from 1892 to October, 1894, daily readings were made. At Pasco, Wash., the Northern Pacific Railroad takes readings and furnishes this office with copies of its records whenever desired. River records made at Riparia, Wash., by the Oregon Railway and Navigation Company (on the Snake River) are also available whenever desired. A record was made in former years at Lewiston, Idaho, but the same appears to have been lost. A brief record for 1892 was made at Ontario, Oreg. A partial record was made by the Union Pacific Railway at Huntington, Oreg., but is not available. Gauges were erected during December, 1894, at Northport, Wash.; Wenatchee, Wash.; Lewiston, Idaho, and Weiser, Idaho.

The gauges at Umatilla and The Dalles, Oreg., were repaired. The river gauges along the Columbia and Snake rivers available for record at this date are at the following places: Northport and Wenatchee, Wash.; Lewiston and Weiser, Idaho; Umatilla and The Dalles, Oreg., and by cooperation with others, Riparia and Pasco, Wash., and Cascade Locks, Oreg.; all of which go to make a complete and satisfactory river service. With a service not nearly so good, this office saved to the merchants of Portland alone, by successful flood warnings issued during June, 1894, the sum of \$240,500, of which there is a record, and many thousands of dollars to others of which there was no record kept.

THE WILLAMETTE RIVER.

This is the main tributary of the Columbia west of the Cascades and drains the fertile Willamette Valley. It is some 200 miles from its source in the Cascades and Calapooia Mountains to its mouth, which is 6 miles north of Portland, where it empties into the Columbia River. It has numerous tributaries; there are about 40 streams that feed it during its course. The main river is navigable for about 100 miles from its mouth.

CAUSE OF FLOODS IN THE WILLAMETTE VALLEY.

The main cause of floods in this valley is the complete saturation of the soil by the rains of November and December; the prevailing high humidity prevents evaporation, so that usually all the rain falling after January 1 runs off and into the rivers, the natural drainage canals—the numerous small streams quickly precipitating the fallen rain into the main river, which, being unable to discharge rapidly enough, produces the rapid rise. In 1881 a flood resulted from the very heavy rainfall, which produced its greatest effect about February 7, on which date the river stood 23.8 feet at Portland, having risen 17 feet in six days. The heavy rainfall occurred on the 1st and 2d of February, and amounted to about 4 inches in forty-eight hours. The heaviest rainfall on record at Portland is 10.61 inches in forty hours on December 12-13, 1882. The forty days preceding this excessive precipitation was comparatively dry, hence a large amount thereof was absorbed by the soil; it was, nevertheless, sufficient to cause the river to rise from 6.5 to 18.5 feet in three days.

Save in one single instance the rainfall alone has not caused the river to rise above 18.7 feet, and in this one instance, viz, February 7, 1881, the rapid increase in temperature during the first few days of February caused the snow in the mountains to melt rapidly and in this way materially assisted the rainfall in causing the flood.

The highest water on record produced by the Willamette River alone occurred on February 5, 1890, when the gauge at Portland showed 28.7 feet. Corresponding high water prevailed through the valley, which resulted in doing damage to the extent of \$1,000,000. This flood followed the heavy rains that fell from January 22 to February 5, during which period 15.67 inches of rain fell at Portland. Just previous to the commencement of this heavy rainfall about 35.3 inches of snow fell, making a total of 19.2 inches of water at Portland, which went into the river in a short time

The precipitation in the Willamette Valley averages about 75 per cent of that at Portland, so that approximately 12.15 inches of water flowed into the river within two weeks' time, and the result was the great spring freshet of 1890. The following highest waters, with dates each year, resulting from purely local causes in the Willamette Valley, will prove of interest:

Year.	Height.	Date.	Year.	Height.	Date.
	<i>Feet.</i>			<i>Feet.</i>	
1880	15.9	January 9.	1888	16.2	February 1.
1881	23.8	February 7.	1889	4.2	January 24.
1882	18.5	December 16.	1890 ¹	28.7	February 5.
1882	14.8	March 4.	1891	6.0	March 28.
1883	16.7	February 2.	1892	12.1	January 5.
1884	12.0	February 25.	1893	18.7	December 4.
1885	15.9	January 9.	1893	8.8	February 14.
1886	17.1	February 4.	1894	16.1	January 23.
1887	15.8	February 1.	1894 ²	18.0	March 19.

¹Special reading at 5 p. m., one hundred and twentieth meridian.

²During April, 1894, the river was from 11.9 to 17.8 feet. On May 2 it was 17.9. It then fell to 15.2 on May 6, and rose steadily to a maximum of 33 feet on June 7.

HISTORY OF THE RIVER GAUGES ALONG THE WILLAMETTE RIVER.

The river gauge at Portland was first established by the city engineer about 1872. The records previous to 1879 are in his possession. On March 16, 1879, observations of the height of the river were begun and a record kept daily by this Bureau which have been kept up ever since. At Oregon City, 18 miles south of Portland, a gauge has been in use for the past five years by the Willamette Pulp and Paper Company, at whose offices a record has been made, during high water only, of the height of the river. A record is supposed to have been made by the lock company at that place prior to that of the paper company, but no trace of it can be found to-day. At Salem a gauge was erected by this Bureau in 1890 and a partial record has been made since at that point. Gauges were erected at Albany and Eugene by the Weather Bureau in 1878 (November), and since then partial records have been made, principally during the winter months. Excellent river gauges, owned by this Bureau, are now located at Eugene, Albany, Salem, and Portland. Gauge readings can be obtained at any time from Oregon City when desired.

FLOODS AT PORTLAND.

Portland is on the Willamette, the river flowing through the center of this city, and is 6 miles from where the river empties into the great Columbia.

About 18 miles south of Portland are Willamette Falls. At Portland the zero of the river gauge is 4 or 5 feet (surveyors differ) above mean low tide at Astoria, 100 miles west.

When the river at Portland stands at 3 feet above zero, there is a tide of 3 feet shown on the gauge at the time of high tide. The lower docks along the river front are from 15 to 18 feet above the zero of the gauge. The cellars of buildings on Front street (the first street from the river) on the west bank are from 17.5 to 19 feet above the zero mark. Hence the danger point begins at about 15 feet, though damage is not done until 17.5 feet are reached. Portland is subject to freshets of the Willamette River, that occur usually about February 1, and to the backwater incident to the rise in the Columbia, which takes place, as a rule, in June. The Columbia rises and prevents the Willamette from discharging its waters into it, and hence this water is backed up to the falls at Oregon City. About 4 miles south of Portland a rapid rise of the land occurs, and the result is that the backwater flood is confined principally to within 10 miles of the Columbia River.

RALEIGH, N. C.

By C. F. VON HERMANN, *Observer*.

The western streams of North Carolina are short and very rapid, and no system of river and flood warnings has been established. Predictions of floods could here only be made from the probability for excessive rains, not from river-gauge readings, as the rise of these rivers is too rapid to enable the stages to be telegraphed to the central office in time for the issue of flood warnings.

The rivers in the east, however, have a much longer course, and flow in the eastern district through alluvial formations still being built up by the rivers themselves. Here floods are sufficiently frequent and destructive to make the system of river and flood warnings established by the Weather Bureau of great value to agricultural and other interests in this section of the State.

The average annual precipitation for North Carolina is nearly 44 feet. The greater part of this large amount of water finds its way to the sea through thirteen large streams. The drainage areas may be classified into three systems: (1) Areas wholly within the State, or nearly so, whose streams reach the ocean within the coast line of North Carolina; (2) the rivers which enter the Atlantic through South Carolina; (3) the areas west of the crest of the Blue Ridge, whose waters finally enter the Gulf of Mexico through the Mississippi River.

1. To the first system belong the innumerable small streams entering the sounds, which have very little fall, generally less than 1 foot to the mile, and five large rivers, the Chowan, Roanoke, Tar, Neuse, and Cape Fear.

The Roanoke, with its tributary, the Dan, is the longest river of the State, and has its sources in the Blue Ridge. Its total length is 300 miles, and it drains the northern counties from Stokes to Northampton. The total area drained probably exceeds 8,000 square miles. A large volume of water enters it through its Virginia tributary, the Staunton. The fall of the Roanoke from Danbury, in Stokes County, to the point of entrance into Albemarle Sound is 700 feet. The river is navigable as far as Weldon. Extensive farms along the lower course of the Roanoke are in some cases protected from floods by embankments; numerous islands which appear during low water are used for stock.

The largest streams south of the Roanoke are the Tar, Neuse, and Cape Fear. The Tar drains eight counties, and is navigable up to Tarboro. The Neuse, rising in the highlands of Person County, flows southeast into Pamlico Sound at Newbern, where the river is over a mile wide.

The Cape Fear River drains the largest area in the State, over 8,000 square miles. The river rises in the northwest corner of Guilford County, pursues a southeast course, and enters the Atlantic 30 miles below Wilmington. The fall throughout its course is over 500 feet. It is navigable for 150 miles up to Fayetteville. When the river is high a large area of farm land is flooded, and lumber and milling interests at Wilmington are also affected.

2. The chief rivers of the second system which flow through South Carolina are the Yadkin and Catawba. They have very similar courses, rising on the eastern slope of the Blue Ridge, flowing first eastward, and then curving sharply southward. The largest of these rivers, the Yadkin, has a length of 250 miles; its fall to the land is 500 feet, and 700 feet more to Cheraw, S. C. Its drainage area is about 5,000 square miles. The Catawba and Broad are important as the sources of the Santee River of South Carolina.

The six rivers of the third drainage system are the Hiwassee, Big Pigeon, Tennessee, French Broad, Watanga, and New. The last takes an unusual course northward into the Ohio River from the northwest corner of the State. The valleys of these streams are inclosed basins, and the waters pass the western mountain barrier through deep and rugged gorges.

3. Some records of high water previous and subsequent to the establishment of river stations, and some remarks on the rapidity or rise and freezing of the rivers of North Carolina.

There is a tradition that the highest stages of the rivers of North Carolina were reached during the great May freshet of 1771.

Very high stages of the Roanoke River occurred in 1862, when the river reached about 38 feet above low water on June 7. On January 5, 1865, Fayetteville reported as 75 feet above low water, but which recent circumstances indicate could not have exceeded 50 feet on the present gauge.

Other destructive freshets occurred May 10, 1873, and September 25, 1876.

The highest stage of the Roanoke ever reached is said to have occurred in November, 1877. The waters touched the highest points ever reported at Danville, Va., namely, 19 feet, and at Clarksville, Va., 27 feet; and on November 26 the stage at Weldon was 48 feet 8 inches, which has not since been exceeded.

Other floods on the Roanoke occurred July 4, 1886, September 13, 1888, and June 1, July 2, and August 3, 1889.

Coming down to times for which authentic records exist, the following data of interest may be mentioned:

At Mount Holly the Catawba River reached the highest stage, 14 feet, August 3, 1887. The danger line is placed at 20 feet. The lowest is 0.2 foot in June, 1890.

At Weldon the Roanoke River passed the danger line, 27 feet, in February, March, April, May, June, and August, 1891; highest, 35 feet, May 31. In 1892 it exceeded the danger line, January 15 to 23; highest, 33.6 feet, on January 16. In 1893 the highest stage reached was 39 feet, September 16. The lowest river was 0.1 foot, October, 1892.

A remarkable rise of the rivers of eastern North Carolina occurred January 9 to 15, 1895, which was successfully predicted by the Weather Bureau. The Cape Fear River, at Fayetteville, reached the highest stage ever known, namely, 58 feet, on January 12, and rose to within 5 feet of the great flood of November, 1877. Owing to the season of the year, comparatively little damage was done.

The rapidity with which the rivers rise requires the greatest vigilance and promptness in issuing warnings. A rise has occurred at Weldon of as much as 25 feet, and at Fayetteville as much as 30 feet in twenty-four hours, the rivers thus reaching the danger line from relatively low stages within a day.

Ordinarily the waters of North Carolina remain open all the year, except the smaller streams in the western district. During severe winters, such as occurred in 1857, 1886, and 1895, all the rivers freeze and even the sounds, except the central portion of Pamlico Sound, and the lower courses of the streams in the southeast corner of the State. In 1893, for instance, Albemarle Sound, from Elizabeth City to Roanoke Island, was frozen from 8 to 14 inches thick from the 2d to the 28th. Currituck Sound was frozen over nearly the entire month. The Cape Fear, at Fayetteville, was frozen over from the 19th to the 27th; the Neuse, at Newbern, 18th to 28th; the Tar, at Tarboro, 18th to 27th; the Roanoke, at Weldon, 17th to 28th. The Yadkin, at Salisbury, and the French Broad, at Hendersonville, were frozen over with ice 10 inches thick. Similar conditions prevailed in the other years mentioned above. Ice gorges are then somewhat common, without, however, doing much damage.

HOW FRESHETS MAY BE PREDICTED.

There is no regularity in the rising and falling of rivers of North Carolina, and no spring floods, as such. The snowfall in the mountains in winter is rarely heavy enough to constitute a special factor in causing floods, for the reason that there can be no great accumulation of snow. What falls one week is sure to melt the next, and the rivers ordinarily remaining open nearly all the year round, conduct the waters from the mountains gradually to the sea. Owing to the uniformity in the distribution of precipitation throughout the year, the flow of the rivers is nearly as full one month as another.

The success of the river and flood warnings in North Carolina will depend to a great extent on the ability of the forecaster to recognize when the conditions become

favorable for heavy rains. Excessive precipitation, and consequent flooding of streams, occurs most frequently, associated with cyclonic disturbances moving from the Gulf of Mexico to Florida and thence up the Atlantic coast, and especially in connection with the regular subtropical storms of August, September, and October. But even the presence of a relatively slight depression over Alabama or Georgia, or off the South Carolina coast, with a high area over New England, will cause heavy rains in the central and eastern parts of the State. Frequently the heaviest rainfall is confined to a limited portion of the State, as, for instance, in August, 1894, when an enormous rainfall occurred in the southeastern portion of North Carolina on the 3d to the 6th. The Cape Fear, at Fayetteville, reached its highest point, 34.4 feet, on the 7th, while the Roanoke was not influenced in the slightest degree.

The distance from Danville to Clarksville, Va., is 55 miles; from Clarksville to Weldon, N. C., is 65 miles. If heavy rains occur at the head waters of the river Dan, the highest stage at Clarksville is reached twenty-four hours after the waters begin to subside at Danville; if the rains extend into Virginia over the drainage area of the Staunton, the highest stage is usually attained at Danville and Clarksville on the same day. The river then reaches the full flood at Weldon within about forty-eight hours.

REDBLUFF, CAL.

By Mr. MAURICE CORNELL, Observer.

The Sacramento River when flooded is very turbulent. The watershed may be divided into two sections, with the dividing line at or near Redbluff. The surrounding lowland of the southern section was once the bed of an inland sea, and, geographically speaking, is of recent formation. The northern section has a more elevated position, is of a rocky or gravelly formation, the valley more contracted, and the gradient steeper. The bed of the river throughout the whole southern section is being constantly elevated by deposits, while the bed in the northern section is being lowered by erosion. It is evident, therefore, that the danger from overflow to lands of the southern section is becoming greater, while with the southern section it is lessening. The "danger line" twenty years ago is not the "danger line" to-day. The watershed of the upper Sacramento is nearly 10,000 square miles. Within the greater part of this area the winter snows accumulate. If this is suddenly converted into water, the greatest danger from floods in the Sacramento is to be apprehended.

At Redbluff great and sudden rises occur generally with periods of protracted rains in the valley, but as soon as the rain ceases the river falls as suddenly as it rose. No great danger need be apprehended on these occasions.

It is when protracted warm rains in the snow-covered mountains tributary to the Upper Sacramento system occur that damaging floods prevail throughout the whole valley.

It is estimated that within the last thirty years not less than \$6,000,000 worth of property has been destroyed by floods in the Sacramento Valley.

For the purpose of flood warnings, there should be a station established somewhere in the snow regions tributary to the upper Sacramento River and a gauge station put in at the mouth of the Pit River. With these precautions taken, the people could have warnings from thirty-six to forty-eight hours in advance. This would give ample time to look up and repair defects in the levees, which are being continuously bored by squirrels and gophers. Owing to the nature of the soil in the levee sections, once the water passes through a gopher hole, there is no stopping it; hence the importance of warnings.

SACRAMENTO, CAL.

By Mr. JAMES A. BARWICK, *Observer*.

The levees surrounding this city will stand a rise of 30 feet before endangering the city. On numerous occasions lands which have good and substantial levees on their river fronts have been submerged by back water from the breaking of the levees either above or below their places. If the levees were continuous from Redbluff to Sacramento and below, it would be an easy matter to predict the river stages at this and other points lower down the river; but as the levee system is at present, a rise of 10 to 15 feet in a few hours at Redbluff would scarcely be felt or noticed at Sacramento. As the great watershed of the upper Sacramento pours its drainage into the Sacramento River, the water spreads over the low tule lands by way of the numerous sloughs and by overtopping the slightly built levees. Had this water been confined to the river proper, it would have caused a considerable rise at Sacramento.

The sudden rises at this point come from the American River, whose mouth is only a mile above the city, while the stream is both short and steep, and therefore the water reaches Sacramento with a rush and raises the Sacramento stream rapidly. The water recedes as quickly. But when the Sacramento is high from continuous rains over the entire watershed of northern and central California, and heavy rains occur on the head waters of the American River, raising that stream quickly, danger is then to be apprehended in this city until the American can discharge its supply of water.

DATA FROM THE REPORT OF A. H. ROSE, COMMISSIONER OF PUBLIC WORKS, 1895.

In the floods of 1853 and 1862, the Sacramento River water extended a broad expanse from the Sutter Fort site, in Sacramento, westward to Davisville, standing 3 feet deep across the natural river banks at and near Sacramento. The steamer course from Stockton to San Francisco was, during the latter flood, a direct line across country from Rough and Ready Island to Antioch.

During the high water of March, 1879, the lowlands of the Sacramento Valley, to the extent of 847 square miles, were covered with water. This area includes all flooded for a short period of time, as well as that upon which the water rested for several months. Above the mouth of Feather River, in what may be called the upper flood region, the area covered was about 483 square miles; and below that point, in what is called the lower flood region, the flooded area was about 364 square miles in extent.

The maximum flow of the Sacramento River would have been—

	Cu. ft. per second.
At Redbluff.....	133, 000
At Colusa.....	89, 000
At (above) Feather River.....	83, 000
At (above) American River.....	136, 000
At Sacramento.....	162, 000

A similar study of the condition which prevailed in January, 1894, when the river at Redbluff, on January 15, rose 4 feet higher than in March, 1879, leads to the following result:

The maximum flow would have been—

	Cu. ft. per second.
At Redbluff.....	152, 000
At Colusa.....	92, 900
At (above) Feather River.....	87, 000
At (above) American River.....	136, 000
At Sacramento.....	156, 000

But the high water of January, 1894, did in fact cause a maximum discharge at Sacramento of only about 54,000 cubic feet per second. The river rose only to 21.5 feet on the Sacramento River rod. Had all the water been confined to the channel, none escaping to any of the basins, the water at Sacramento would have been far higher than of the great floods of the past.

That the water surface in 1894 at Sacramento was lower than that of March, 1879, is explained by the fact that in the one case the several flood basins were well filled with water; in the other way they were practically empty at the commencement of the rise, and were therefore practically efficient in retarding the passage of the flood wave down the valley. The highest stage at Sacramento was not reached until January 21.

ST. LOUIS, MO.

By Mr. H. C. FRANKENFIELD, *Local Forecast Official.*

The drainage areas of the principal Missouri River tributaries are given below. Of the rainfall which occurs in the Missouri Basin only 15 per cent finds its way into the river, the remainder being taken up by dry winds and absorptive sandy soils; while in the Upper Mississippi and Ohio basins the percentage is 24.

The tributary effect is very uncertain, as it depends upon the stages of water in the different rivers affected. If the receiving stream is at the high-water stage the effects of a rise in the tributary streams would be totally different from those produced when the receiving stream is low. Consequently the figures given below are largely estimated, and represent what are considered only as average effects.

The tributary effect upon the Missouri River within the State of Missouri is very considerable at times. The tributaries of importance and their respective drainage areas are as follows: On the north side, the Grand River, 7,826 square miles; Chariton River, 3,156 square miles; on the south side, the Black River, 2,732 square miles; La Mine River, 2,700 square miles; Osage River, 15,200 square miles, and the Gasconade River, 3,800 square miles. The first four of these rivers discharge into the Missouri between Kansas City and Boonville, and the amount of their effect can not be estimated to within a reasonable degree of accuracy on account of the absence of the Weather Bureau gauges at or near their mouths. Their additions to the main stream are evidently not quite as large as those of the rivers east of Boonville, especially those of the Chariton and Grand rivers on the north side. These drain a region over which the average rainfall is several inches less than that of the region south of the Missouri, and they consequently furnish less water; the Grand River furnished the major part. The tributaries east of Boonville—the Osage and Gasconade—drain a considerably larger area, and flow through a region which is favored in the matter of rainfall when compared with the north half of the State. The effects of rises in these two rivers appear as a deflection on the Hermann gauge, the normal gauge relations between Boonville and Hermann being disturbed. About one-eighth of the amount of a rise at Bagnell, on the Osage, would appear as an abnormal increase on the Hermann gauge about two days later, and the same proportion is about correct for the Gasconade based upon the stage at Arlington, the rise reaching Hermann in about one and one-half days. Although the area drained by the Gasconade is small, the descent to the river basin is sharp, and it receives water very rapidly, and in much greater quantity, comparatively, than in more level regions.

The principal tributaries of the Mississippi River between Davenport and St. Louis are the Des Moines, Illinois, and Missouri rivers. The Des Moines River does not contribute any considerable volume to the Mississippi, and the effect on the Warsaw gauge at high water would probably not amount to more than one-eighth or one-sixth of a rise just above its mouth. The effect of the Illinois River upon the main stream is somewhat greater, but the absence of a sufficient number of observations at Grafton, Ill., prevent an accurate estimate at this time.

The greatest amount of water contributed to the Mississippi River comes from the Missouri, and it is the controlling factor in floods below Alton, Ill. Of the water which passes St. Louis the Missouri probably contributes from about 55 to 60 per cent at a 13-foot stage, and from about 67 to 70 per cent at a 20-foot stage. That is of course assuming that the stages in the two rivers are approximately alike. The greatest floods occur at St. Louis when both rivers are at a flood height at the same time. Fortunately this condition of affairs is quite infrequent, having occurred but four times during the past fifty-one years, namely in 1844, 1851, 1858, and not again until 1892. In 1844 the highest recorded stage, 41.4 feet, occurred. The floods from the Missouri River as a rule occur later than those from the Mississippi. Of these the greatest occurred in 1883 and 1892.

In the Missouri River Basin during extreme low-water rainfalls of an inch or less produce little or no effect upon the river, for what the soil does not take up is absorbed by the sand in the river. This, of course, is true of only a single rainfall. A second and third in close succession would produce the usual rise.

The scarcity of gauges on the Missouri River, and the absence of discharge figures from a sufficient number of places on both rivers, prevent more accurate deductions, and more or less interfere with the accuracy of forecasts. Hydrographs have not been found to be of much service.

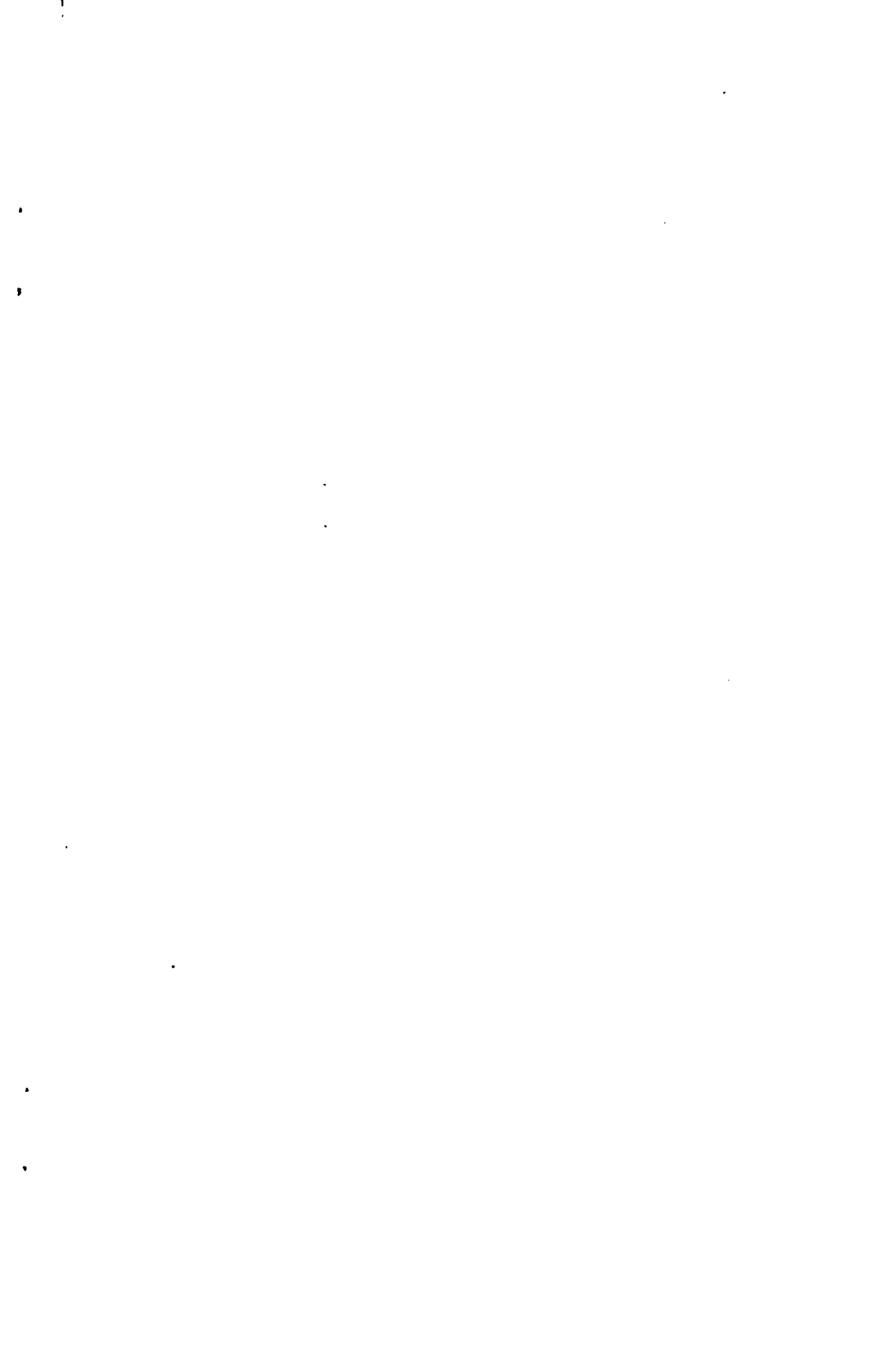
In the vicinity of St. Louis, on both sides of the river, there is no danger of damage by water up to a 30-foot stage. Practically everything is protected up to a 34-foot stage on both sides, with the following exceptions: Even as low a stage as 20.2 feet on the St. Louis gauge will cause the water to run into the marshes on the Illinois side below the East St. Louis Waterworks, but with no resulting damage, and a 32-foot stage will cause the backwater in the Cahokia Creek to overflow its banks and cover the lowlands to the south and east of St. Louis.

At Warsaw, Ill., the new levee protects everything up to an 18-foot stage on the Illinois side, while on the opposite side about 14 feet on the Warsaw gauge will cause an overflow in the Des Moines River bottoms.

At Hermann, Mo., while the danger line is at 21 feet, at which stage the upper bottoms are submerged, at a 16-foot stage some of the lower bottoms are submerged. I would also respectfully invite attention to the following remarks concerning the Hermann gauge, being an extract from the report of the Missouri River Commission for 1894 (Appendix Y Y of the Annual Report of the Chief of Engineers for 1894): "The zero elevation of the Weather Bureau gauge at Hermann is at present 71.23 (above St. Louis directrix); but this value only holds good up to the 13-foot stage, above which the gauge is wrongly graduated, each foot recorded being actually equal to 0.876. According to the rule adopted by the Commission, the Hermann gauge should read from a zero of 68.35. The zero of this gauge has not been kept constant, having been as low as 67.34 previous to 1886, when it was changed to its present elevation." I would suggest that in future publications the zero of this gauge be given as 68.35 feet above St. Louis City directrix, in accordance with the above, instead of 71.7 feet, and that a correction of 2.88 feet be applied to future readings up to the 13-foot stage, and a correspondingly larger one above that stage until the gauge can be repaired. This can probably be done during the next month if the water is sufficiently low. The error above the 13-foot stage probably arose from the fact that the gauge was graduated to inches, approximately, instead of to tenths of feet when it was placed in position some years ago.

A new water record was made at St. Louis on January 27, 1895, when a stage of 0.7 foot was observed.

A brief description of the system of river forecasting in use at this station may be of some interest. The system is the one elaborated and perfected by Mr. James A. Seddon, assistant engineer of the Missouri River Commission, to whom I am indebted for much valuable information concerning the Missouri River. The system was also used last year by Mr. Hammon, and is as follows: To determine the gauge relations between any two points on the same river, take a piece of cross-section



Date.	Actual stage.		Forecasted stage, Hannibal.	Difference.
	Keokuk.	Hannibal.		
1892.				
Apr. 20	8.6			
21	9.3	11.1		
22	9.7	11.7	11.8	0.1
23	9.4	12.1	12.1	0.0
24	9.0	11.6	11.8	0.2
25	8.6	10.9	11.2	0.3
26	8.0	10.2	10.5	0.3
27	7.6	9.6	9.7	0.1
28	7.2	9.0	9.2	0.2
29	6.7	8.5	8.7	0.2
30	6.4	8.2	8.1	0.1
May 1		7.8	7.9	0.1
Mean difference				1.6 .016

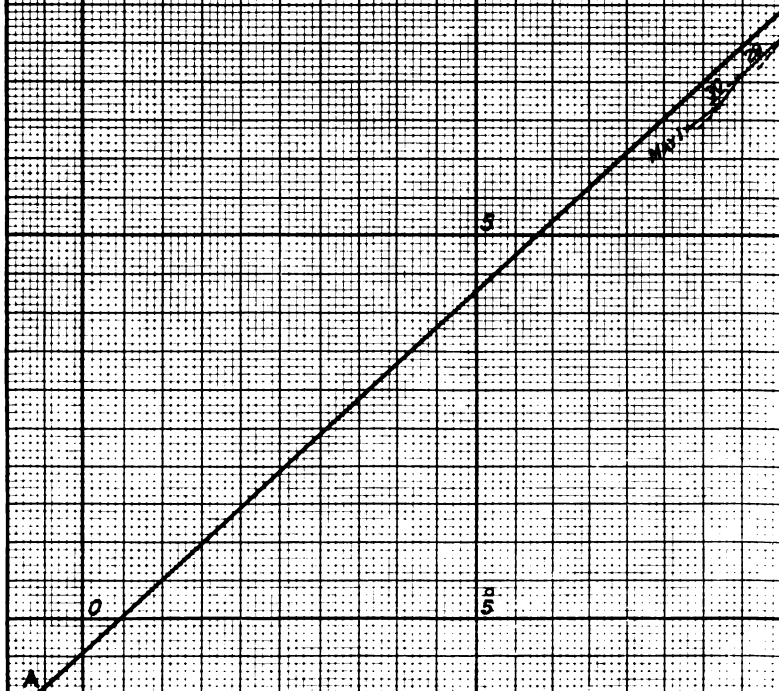
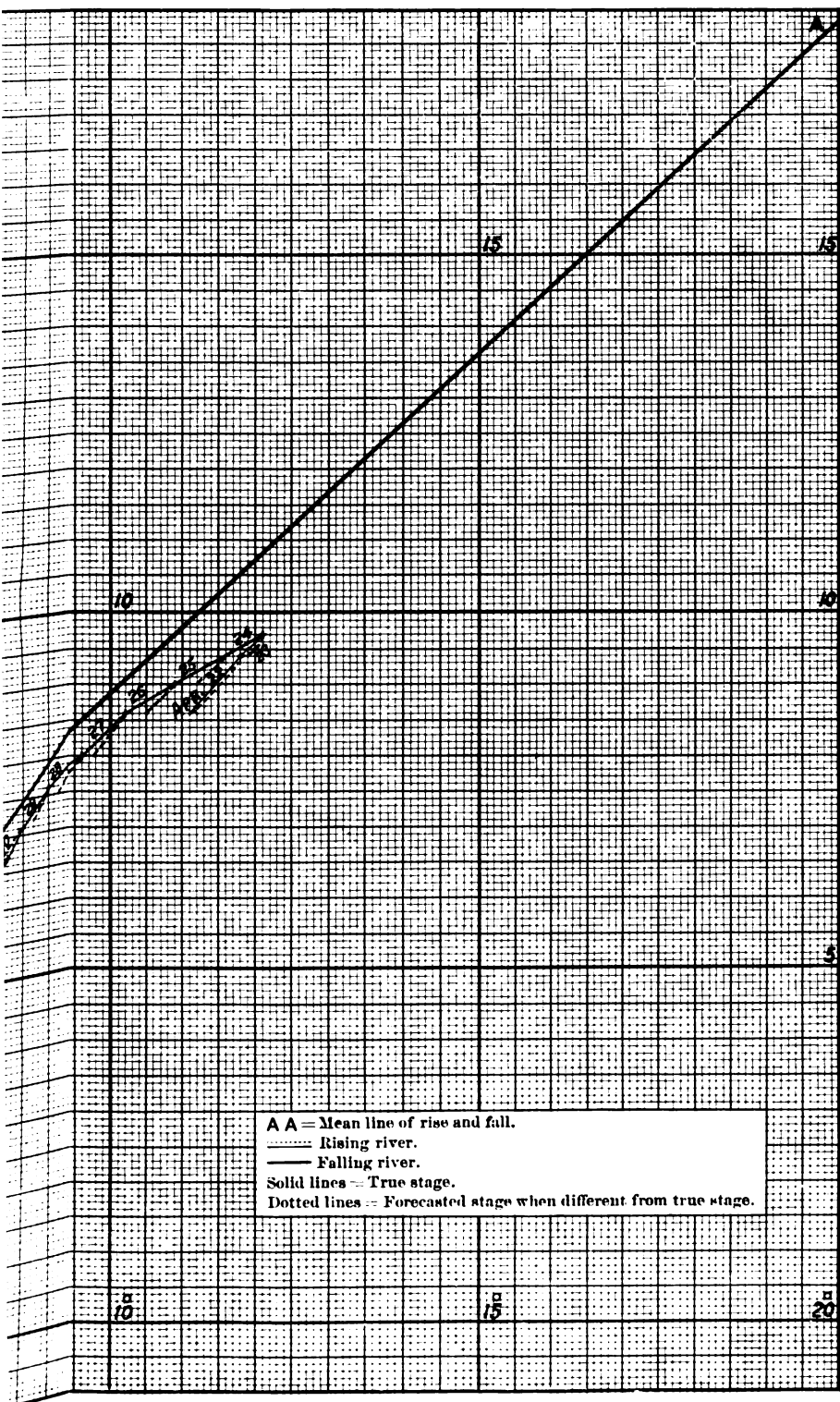


FIG. 3.—SYSTEM OF RIVER FORECASTING—



paper, let the perpendicular scale of ordinates represent the gauge readings at the upper station, and the horizontal scale or abscissas the lower station. The time interval of the water between the two is of course known. Let us assume the time to be one day. Find the point on the cross-section paper corresponding to the gauge reading at the upper station on the first day of the month, and that of the lower on the second day; then find the point for the second day's reading at the upper station, and the third day at the lower one, and so on, connecting each two points by a line, a black line for a rising and a red line for a falling river. Let this be done each day for a year, and then a diagonal straight line of rise and fall can be drawn, along which the stages of the two rivers will invariably meet, if there is no tributary effect between the two and no heavy local rainfall at the lower station. This diagonal line should be a minimum line; that is, one affected by the river itself without tributary or rainfall influence. If lines are drawn for a series of years, a mean line can be obtained which will give better results. With the mean line once obtained, forecasts are made as follows: If the stations are one day apart, as Keokuk and Hannibal on the example inclosed, find the point corresponding to the first day's reading at the upper station, or the ordinate, and the second day's reading at the lower one, or the abscissa. Then find the ordinate corresponding to the second day's reading at the upper station, and trace it horizontally until a point on the abscissa is reached, which, if connected with the point first determined, will make a line parallel with the mean line. This point on the abscissas will be the reading of the gauge at the lower station on the third day, or one day in advance. If several upper stations are used in turn, an accurate forecast for four or five days in advance can be made, unless heavy rains intervene. Tributary and rainfall effects produce a prolongation of the abscissas, and must be estimated as closely as possible. By this system stages can be forecasted to within one or two tenths of a foot for several days in advance.

The system is exemplified on the accompanying chart (see fig. 3) the Keokuk and Hannibal mean line being used with one day interval.

On account of the proximity of the mouth of the Missouri to St. Louis, a combination of discharge figures with gauge relations at Hermann and Grafton is used in forecasting the stages at St. Louis, and forecasts are made for a period of four days in advance.

The time intervals between the stations in this district are approximately as follows:

Mississippi River.—Davenport to Keokuk, 2½ days; Hannibal to Grafton, 2 days; Keokuk to Hannibal, 1 day; Grafton to St. Louis, 1 day.

Missouri River.—Kansas City to Boonville, 1.5 to 2 days; Bagnell to Hermann, 2 days; Hermann to St. Louis, 1 day; Boonville to Hermann, 0.7 to 1 day; Arlington to Hermann, 1½ days.

ST. PAUL, MINN.

By Mr. P. F. LYONS, Local Forecast Official.

The Mississippi River at St. Paul is made up of its own water and that of the Minnesota River, the mouth of the latter being about 7 miles above. Both streams are practically within the boundaries of this State. The Mississippi, having its source in the northern part, has the greater watershed, which is, according to the latest determination of the United States Engineer Corps, 19,730 square miles. The elevation of its head water, Lake Itaska, according to Minnesota State surveys, is 1,457 feet above sea level. It drains the timbered, lake, and marsh regions. The Minnesota, with a watershed of 16,350 square miles, part of which is the Dakotas, has its source practically in Big Stone Lake, at an elevation of 962 feet, and drains the prairie and rolling portions of Minnesota and the westerly adjoining State of South Dakota.

The accumulation of snow and ice during winter is the main cause of floods in these streams, and they usually occur in from twelve to thirty days after the breaking up of ice, or the opening of the river, the average date April 1. As a rule, about

the time of "opening" a marked rise is observed; it continues to about the middle, and occasionally to the end, of April, but the latter is exceptional; generally the crest of the rise is felt about the middle of that month; but should the rainy season set in early in April, and be rather heavy and continue over to May, the danger of an overflow will not only be considerably increased, but its duration will be extended to May. From the records, and by comparisons, it is found that the most potent factors in promoting dangerous floods are as follows: An unusually wet fall, as to fill up lakes and other water storage places, then a severe freeze, a long and steady winter with considerable and steadily accumulating snow. Such conditions are on record for 1880 and 1881, and the greatest flood on record resulted in April, 1881, and almost solely by the liberation of the ice and snow bound waters of the preceding winter, for the rainfall that spring was very light.

On the contrary, January thaws, which are not uncommon, and February and early March thaws, which are frequent, tend to prevent flood. Clear to fair and very dry weather, and it is unusually dry when clear in early spring—or "breaking up time," as it is familiarly called—is also a mitigating condition, as under such conditions a vast amount of snow is carried away by the high evaporating power of the air; this especially true for the watershed of the Minnesota River. During the "spring rise" the water from the Minnesota can generally be detected here by the muddy and turbulent action. When these signs subside and the river continues high or rising, it may be concluded that the Mississippi is rising and that the Minnesota is falling. There are no observations whatever made of either stream above here, and nothing reliable can be learned as to their condition. A large volume of water liberated from near the head waters of the Minnesota is usually felt here in from five to eight days, and one from about the source of the Mississippi, in from seven to ten days. Fresh to brisk north to northwest winds tend to accelerate and hasten the arrival here of a rise, and conversely as to wind, etc.; however, during the snow-melting time counter results are probable, inasmuch as winds in former instances are liable to be cold and tend to check "thaw," while southerly winds are usually the reverse.

SIoux CITY, IOWA.

By Mr. U. G. PURSELL, *Observer*.

The Missouri has two annual rises or periods of high water, the first occurring usually in March, accompanied by the breaking up of the ice, and resulting from the spring freshets, the melting of snow in the valleys, and the spring rains, and is not likely to result in much damage to property unless ice gorges are formed of such extent as to back the water out of the channel. At the time of the highest water known in the Missouri at this place, which occurred in 1881, such a gorge formed at Yankton, S. Dak., causing the water to spread over the lowlands of Clay and Union counties, S. Dak. In this city very little damage was done. At the mouth of Perry Creek, where the river gauge stands, the river kept within its banks, but it covered the flats in the lower part of the city with backwater, having but very little current and doing but little damage. At the present time that section of the city is covered with houses, and the stage of water would cause serious inconvenience to a large number of people, though little property would be carried away or destroyed.

The second annual rise occurs in June or the first days of July, and is commonly known as the "June rise." It is believed to result largely from the melting of the snow in the mountains, but the rainfall of May and June, being usually the heaviest monthly rainfalls of the year in this section, must contribute a large part of the water in the June rise. A very close estimate of the water in the June rise can be made by considering the amount of accumulated snow in the mountain districts with the spring temperatures. Variable temperatures allow the snow water to drain off gradually, while steady high temperatures bring it down with a rush.

The principal tributaries of this section of the Missouri are the Big Sioux, Vermillion, Dakota, Grand Owl, Cheyenne, Bad, White, Niobrara, Floyd, Little Sioux, and Maple rivers. The most destructive flood in the history of this city was that of

May 18, 1892, in which the water came entirely from the Floyd River, the Missouri showing but a slight rise from the water emptied into it at this time.

From past experience it would appear that the danger to life and property at this place is greater from a flood in the Floyd than from the highest stages of water yet reached in the Missouri. A very destructive flood occurred in the Little Sioux and Maple rivers June 23, 1891, far exceeding any previous occurrence of this kind. So any of the streams mentioned above might under certain conditions be converted from a brook into a mighty river, going beyond its banks, and filling the whole valley through which it flows. This is especially true of the northwestern Iowa rivers, which have narrow valleys, and which drain a nearly treeless region, with numerous small branches which deliver the water of a heavy rain or a melting snow quickly to the main stream.

VICKSBURG, MISS.

By Mr. R. J. HYATT, *Local Forecast Official.*

The most prominent feature of the work at this station consists in forecasting the approach of high water when dangerous stages of the river are anticipated and crevasses in the levees are feared. In order to forecast intelligently it is necessary to calculate the changes in the upper streams (in connection with the amount of precipitation), including the Ohio and its tributaries, the Missouri, the Upper Mississippi, the St. Francis, the White, the Arkansas, and the Yazoo rivers.

The principal rises in the Lower Mississippi come out of the Ohio, and require about six days en route from Cairo to Vicksburg, four days from Memphis, three days from Helena, and two days from Arkansas City. A rise from the Arkansas at Fort Smith requires about the same time to reach Vicksburg as a rise at Cairo, about six days, and four days from Little Rock. A rise from the White River at Newport takes about four days to reach Vicksburg, and a rise from the Yazoo at Yazoo City about one day.

The St. Francis River and basin complicate the river situation considerably between Helena and Vicksburg, acting as a reservoir for the water during high stages, and holding the river at high water some time after a fall is reported above Helena by pouring an immense volume of water into the river at Helena, and forming a partial dam at that point, retarding the flow of the water in the Mississippi from above. The water from the Mississippi begins to run into the St. Francis basin at a stage of 36 feet on the gauge at Helena, and 29 feet at Memphis. In a similar manner the water from the lower tributaries when high also have the effect of banking up the river above and holding it at an abnormal height, especially when a rise in the Mississippi is coming down. A little effect is produced also in the tributaries by a decided rise in the main river, which causes the smaller streams to back up for a considerable distance.

The rate of movement of falling water is somewhat slower than the progress of the flood wave. The rapid approach of a severe cold wave following a rain storm will generally freeze the upper streams and prevent the water reaching the main river.

From the foregoing it will be seen that a warning of about one week can be given to parties along the river of an impending rise in the Lower Mississippi, thus enabling them to prepare for the flood in advance.

With the exception of the St. Francis, the rivers between Memphis and Vicksburg are navigable. The ice on the river north of Vicksburg caused a temporary suspension of navigation during the month of February, 1895, but it is a very unusual occurrence. The bar at the mouth of the Yazoo River is a very serious obstruction during low water, and at times completely closes the river to navigation from the Mississippi. This obstacle is about to be surmounted by a new channel to be made by the United States Engineer Office which will turn the course of the Yazoo River southward and make it pass in front of Vicksburg through the canal recently dredged from Kleinston about 2 miles below the city, allowing the Yazoo to discharge its waters into the channel of the Mississippi at deep water, insuring naviga-

tion during the entire year. This work is now well under way and it will improve navigation of the Yazoo and change the geography of this locality.

At the present time Vicksburg is not approachable by boat during all seasons of the year from the Mississippi on account of the "cut-off" or change in the course of the river, which necessitates the landing of steamboats at the "lower landing" at Kleinston, where the wharf boat is located. At a stage of 17 feet on the gauge, on a rising river, boats come up to the city front through the canal or "passes" leading to the main river. The improvement in the Yazoo River mentioned above will also afford Vicksburg a deep-water channel throughout the year, allowing steamboats to reach the city front at all times. There are two river gauges at Vicksburg, one at the elevator of the Anchor Line, at the foot of Crawford street, and the other at Kleinston. The former is only available at stages of 20 feet and over.

The lowest water on record occurred during the past year, 1894, when the river at Vicksburg fell to 5.2 feet below the zero of the gauge, on November 9 to 14, inclusive. The highest water at Vicksburg of record is 51.1 feet, on April 27, 1862, making an absolute range of 56.3 feet.

The river north of Vicksburg is inclosed by levees, except at the confluence of the Yazoo, Arkansas, White, and St. Francis. The levees on the left bank, or Mississippi side of the river, have withstood the ravages of the floods during recent years, but those on the right bank have been broken by the force of the water and inundated valuable farm land at considerable loss to planters. The damage to the levees, however, has been rapidly repaired, and now bids fair to stand the floods of future years.

Crevassees in the levees are caused by defects in the construction of the levee, crawfish boring through the earthwork, and sometimes by parties cutting the levee for the purpose of floating logs or to relieve the pressure on one side of the river by cutting the levee on the opposite side. Flumes placed in the levee on rice plantations are also fruitful sources of crevassees. The levees are generally sodded for protection against the action of the water. Revetments are also made for protecting the levee, and planks, bags of earth, and burlap are used for holding the embankment intact.

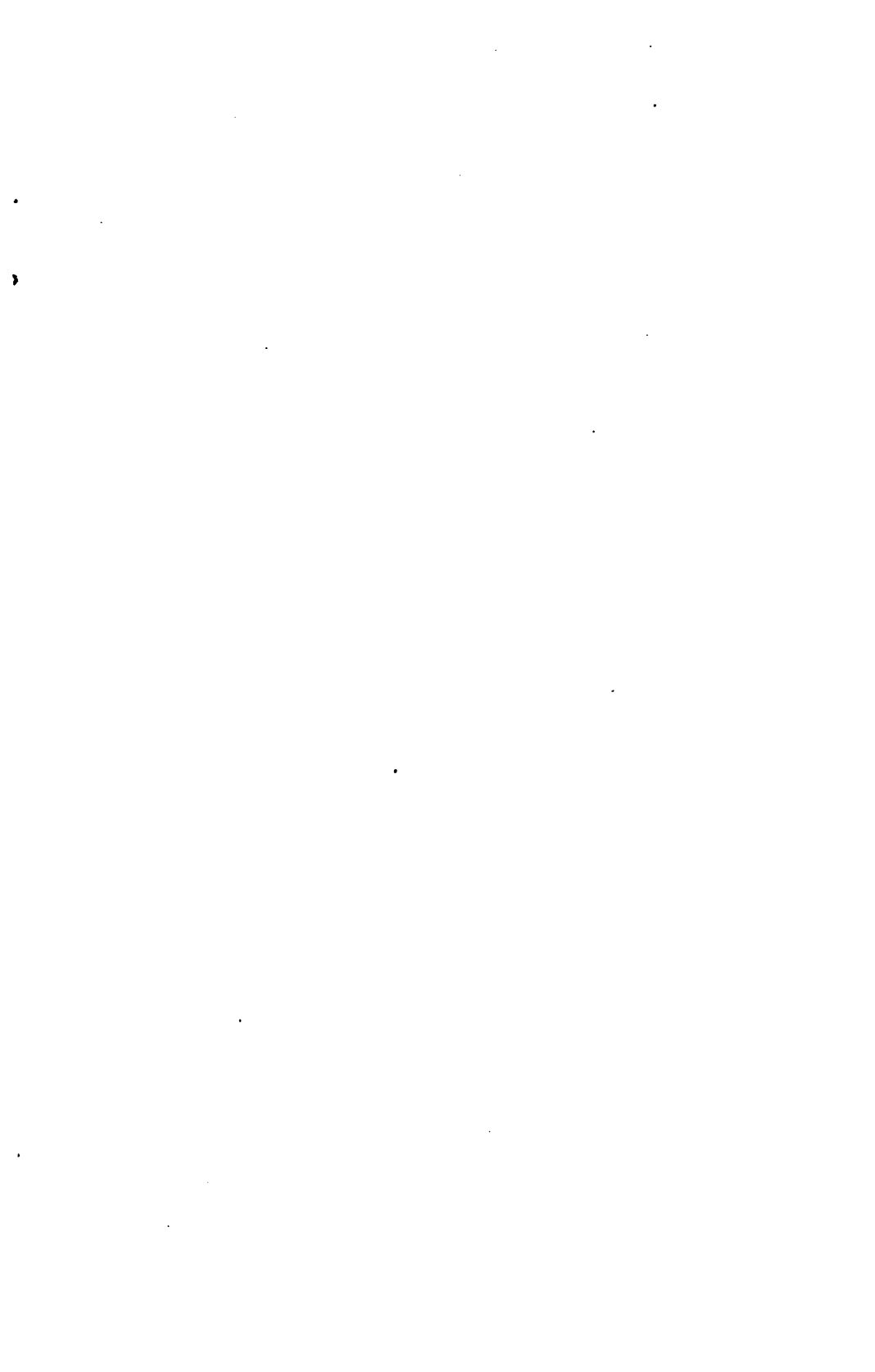
This office is in daily communication by telephone with the levee boards and engineer officers along the river having supervision of the levees and river work, and the river and weather reports are constantly consulted by all interested parties. The river work of the office is greatly appreciated, and the public repose entire confidence in the reports.

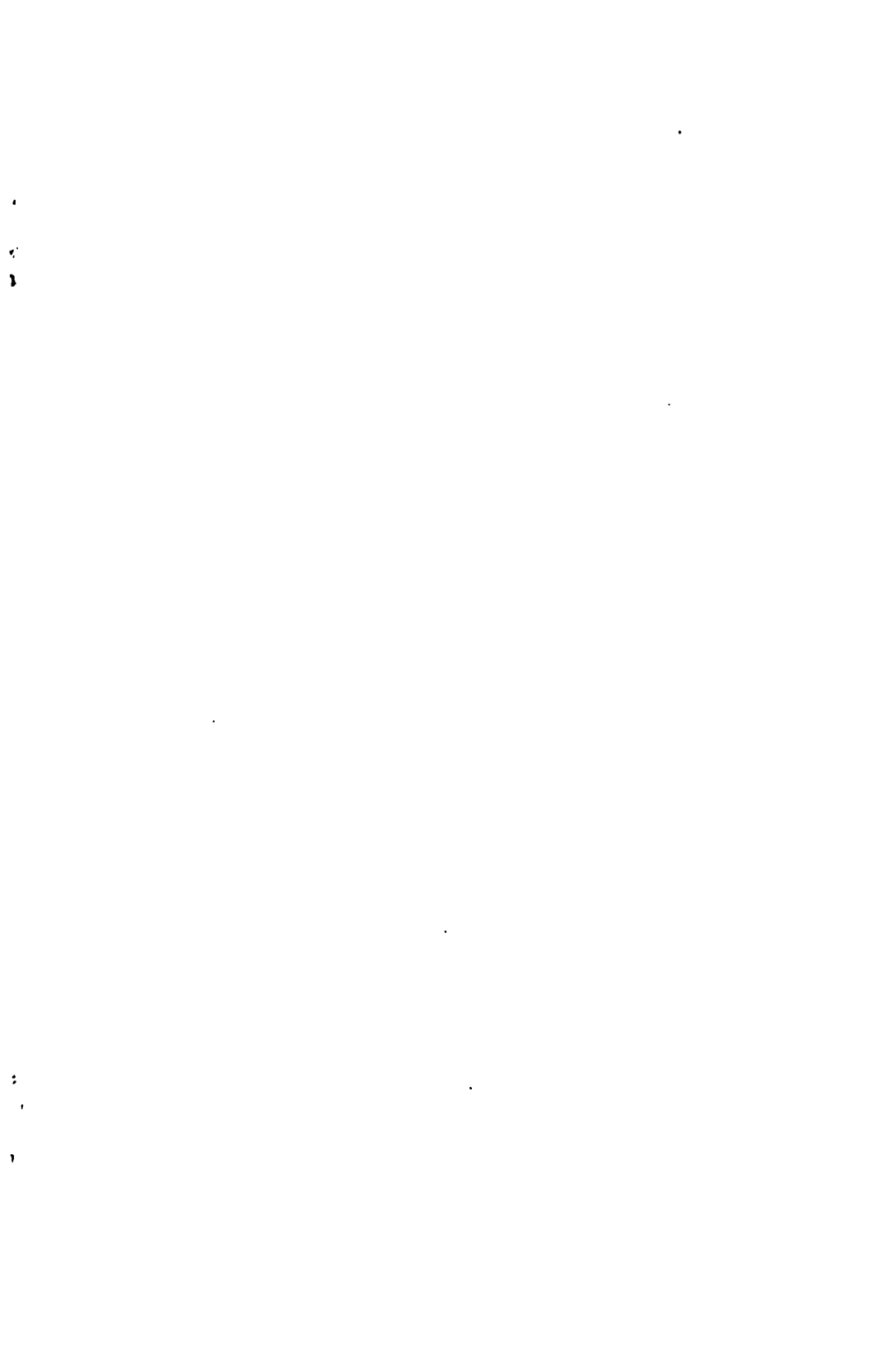
YANKTON, S. DAK.

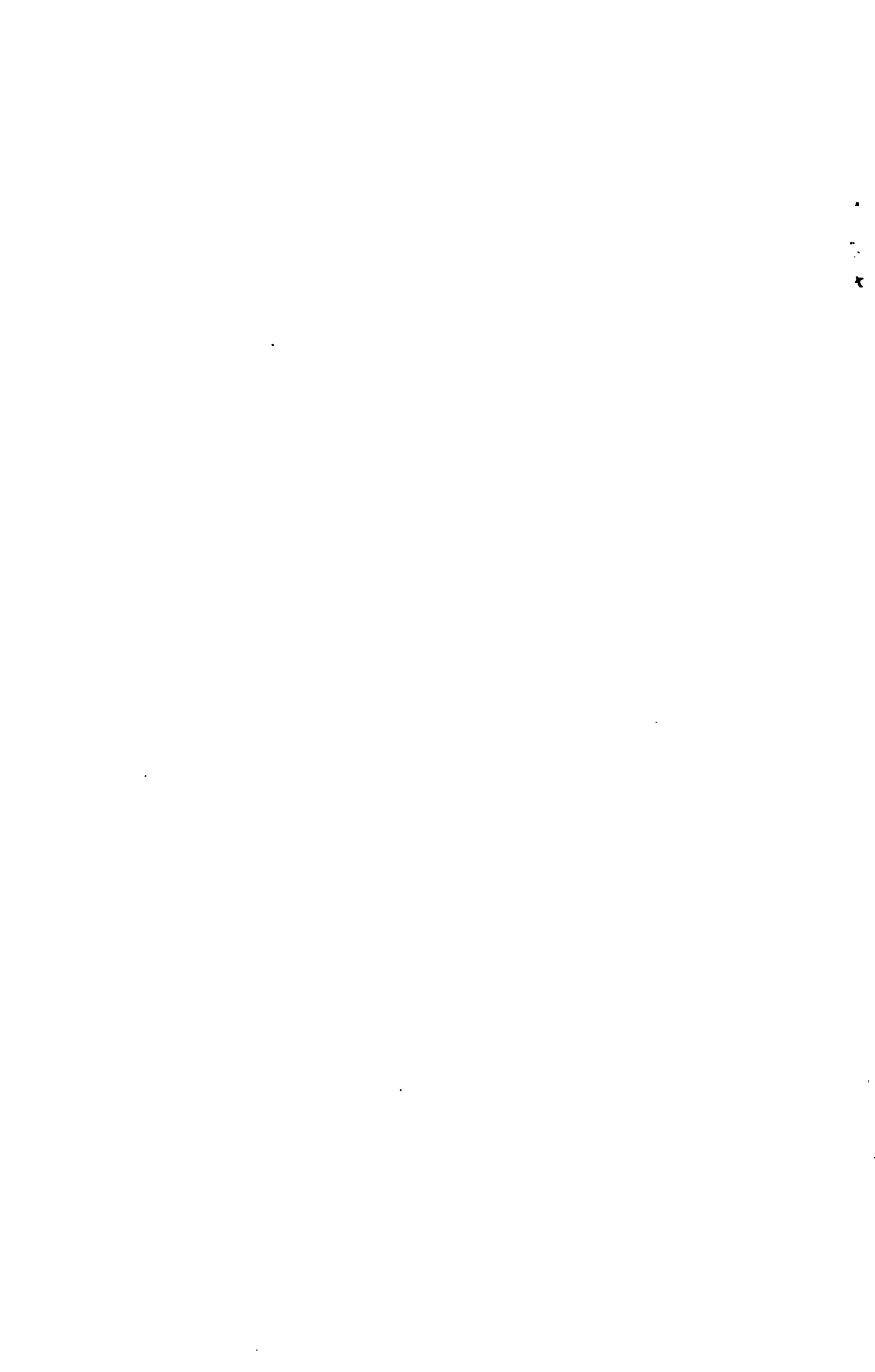
By Mr. H. G. B. SWINBOR, *Station Agent.*

The principal tributaries to the Missouri affecting this locality are the Nebraska, the Cheyenne, and the White rivers, all of which lie on the west of the Missouri and drain the Black Hills country in western South Dakota and eastern Wyoming. It is the large quantity of melted snow brought down by these and other rivers in the spring that causes the annual rise of the Missouri known as the June rise. Sometimes, after a season of excessive snow fall followed by sudden warm spells in early spring, the heavy flow of melted snow and broken ice from these rivers will cause the ice in the upper reaches of the Missouri to break up, while that farther down the river is still intact. This is productive of ice gorges in the narrow parts of the river, at sharp bends, or where numerous sand bars occur, sometimes to such an extent as to cause dangerous and destructive floods. It is generally supposed that the upper Missouri is the source of supply of the extensive artesian basin (or series of basins) which underlies this portion of the country. This would seem to be confirmed by the fact that the pressure of our artesian wells is decreasing as more borings are made, showing that the supply is a limited one.

There is an old Indian saying that a cyclone can never occur between the Missouri and the Jim (or Dakota) rivers, and certainly there is no record of one in this section. The influence of these rivers in this respect would be an interesting study.







University of Michigan

BULLETIN No. 18.—W. B. No. 90.

U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

REPORT

OF THE

FOURTH ANNUAL MEETING

OF THE

AMERICAN ASSOCIATION OF STATE WEATHER SERVICES;

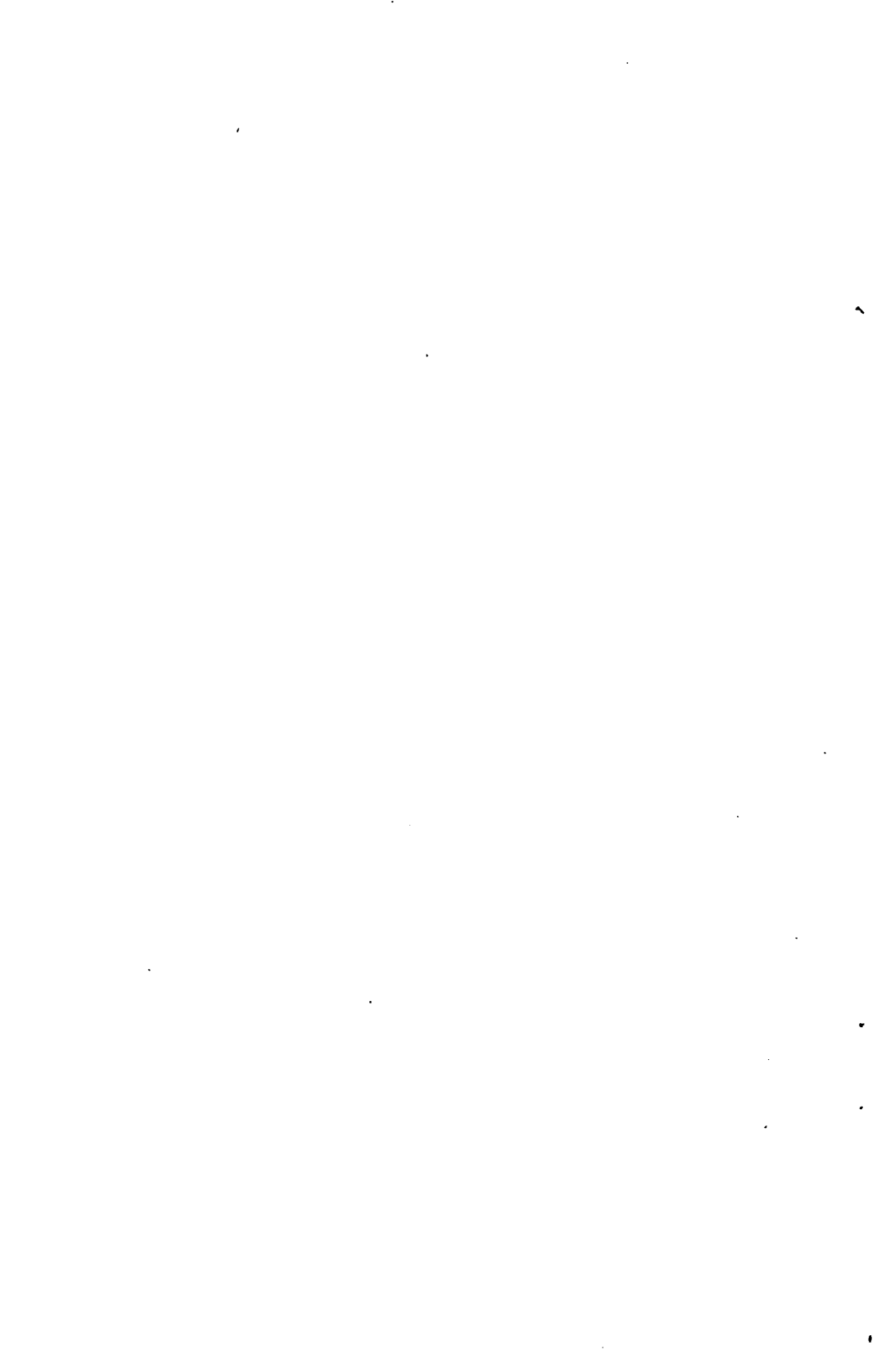
COOPERATING WITH THE WEATHER BUREAU,
U. S. DEPARTMENT OF AGRICULTURE,

HELD AT

INDIANAPOLIS, IND., OCTOBER 16 AND 17, 1895.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.



LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., February 1, 1896.

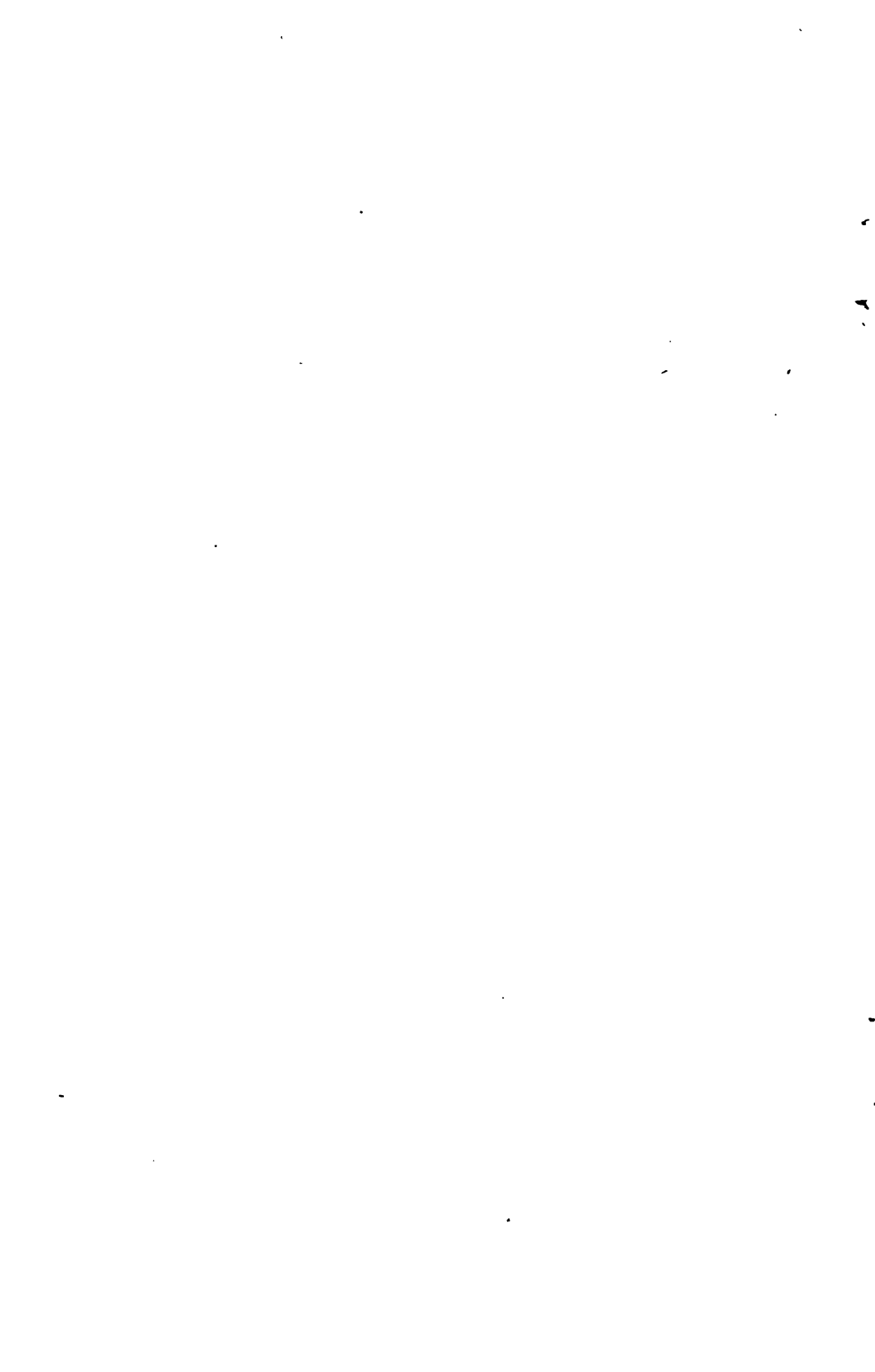
SIR: I have the honor to transmit herewith, with request for authority to have printed in pamphlet form 5,000 copies, Report of the Proceedings of the Fourth Annual Convention of the American Association of State Weather Services, held in Indianapolis, Ind., October 16 and 17, 1895.

This report will prove of interest to the large number of voluntary observers and others cooperating with the Weather Bureau in voluntary capacity, upon whose services the Bureau relies largely for data used in some of its most important work. The proceedings of the three preceding conventions have been published by the Department, and have proved of much interest to those cooperating with the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,
Chief of Bureau.

Hon. J. STERLING MORTON,
Secretary of Agriculture.



CONTENTS.

	Page.
Announcement of annual meeting	7
Topics for discussion	8
Weather service officials and others in attendance	9
Address of the president	10
Discussion at Wednesday morning session	13
Discussion at Wednesday afternoon session	21
Discussion at Thursday morning session	28
Proceedings at Thursday afternoon session	34
Biographical sketch of Increase Allen Lapham	36
Importance of static electricity in Weather Bureau work	39
How best to secure and retain the services of voluntary observers	42
State weather services: their importance and equipment	44
History of the southern California weather crop bulletin	46
Discussion of topics by C. F. von Herrmann	47
Report of committee appointed to investigate the subject of stamping weather forecasts on mail matter	51

FOURTH ANNUAL CONVENTION OF THE AMERICAN ASSOCIATION OF STATE WEATHER SERVICES.

It was originally intended that this association should hold its meetings annually with the American Association for the Advancement of Science, and of the four previous meetings two have been so held, namely, the Rochester convention of 1892, and the Brooklyn convention of 1894. In 1893, and again in 1895, it was found impracticable to meet with the American Association for the Advancement of Science. While the meeting of 1894 was a successful one, the small attendance clearly demonstrated the disadvantages of holding the annual meetings in a city not centrally located. As the American Association for the Advancement of Science met in Brooklyn in 1894, the president and executive committee were of the opinion that if the convention were held in Boston in 1895 the attendance would not exceed that of the Brooklyn convention, and after carefully considering the matter, Indianapolis was chosen as the place of meeting for 1895. As a further advantage, it was decided to hold the meeting of 1895 about the middle of October, after the close of the crop season, when it would be more convenient for the directors of the several services to leave their respective stations. Previous meetings had been held in August. The time fixed for the convention was Wednesday and Thursday, October 16 and 17, the announcement being made on July 12 by the following letter, which was addressed to all State weather service officials:

ANNOUNCEMENT OF ANNUAL MEETING.

AMERICAN ASSOCIATION OF STATE WEATHER SERVICES,
Washington, D. C., July 12, 1895.

SIR: The fourth annual convention of the American Association of State Weather Services will be held at Indianapolis, Ind., Wednesday and Thursday, October 16 and 17, 1895. It was the intention to have the fourth meeting of the association held in Springfield, Mass., in conjunction, as in former years, with the American Association for the Advancement of Science, but in view of the fact that three of the four previous State Weather Services conventions have been held in Eastern cities, it is considered but fair to the directors of the services in the central and western portions of the country that a place of meeting for this year's convention be selected that could be more conveniently and economically reached. Many of the directors, in replying to the letter of April 22 from the president of the association, in which it was proposed to meet in San Francisco, expressed preference for some city in the central portion of the country, and it is believed that in the selection of Indianapolis the wishes of a majority of the directors will be met.

The Chief of the Bureau is anxious that the forthcoming meeting shall be a successful one, and authorizes me to say that as the object of these conventions is to increase the usefulness of the Bureau, permission to attend the convention will be granted all Weather Bureau officials on State weather service work, the necessary absence not to be charged against annual leave.

Information as to hotel accommodations and the building in which the convention will be held will be announced later.

You are respectfully requested to forward to the secretary as soon as convenient a list of topics for consideration of the president of the association in the preparation of the programme of subjects to be discussed at the coming meeting.

Papers upon topics of interest to State weather services are solicited, and if authors of such articles as may be prepared find it impracticable to attend the convention they are requested to forward to the secretary any paper that may be prepared.

Please advise the secretary as early as practicable as to whether it is your intention to attend the convention.

Very respectfully,

H. H. C. DUNWOODY,
President.

The wisdom of selecting Indianapolis as the convention city and delaying the time of meeting till after the close of the crop season was clearly shown by the attendance, which was by far the largest of any meeting held since the organization of the association. The directors of 30 of the 42 organizations were present. Indiana, Iowa, and Nebraska were represented by both the State director and Weather Bureau assistant. Besides the aforementioned, there were present Prof. Willis L. Moore, Chief of the Weather Bureau; Maj. H. H. C. Dunwoody, assistant chief of the Bureau and president of the association, and Mr. James Berry, secretary and treasurer, and chief of the State weather service division of the Weather Bureau.

After correspondence with the various State service officials and securing their suggestions as to the subjects to be discussed, the following programme was adopted:

TOPICS FOR DISCUSSION.

1. How best to secure and retain the services of voluntary observers.
2. What can be done to improve weekly weather crop bulletins and increase their value? What interests are being served by these publications?
 - (a) Should not selected voluntary observers be given authority to telegraph State centers reports of rainfall or other important information on the afternoon preceding date of issue of crop bulletins, thereby giving data for a State rainfall chart?
 - (b) Best means for the collection of data and best form of publication and distribution.
3. Monthly publication of State weather services.
 - (a) Form of publication.
 - (b) Importance of prompt issue.
 - (c) Character of information.
 - (d) Uniformity in style.
 - (e) Preservation in convenient form for reference of the most important data from voluntary observers' records.
4. Distribution of forecasts and special warnings.
 - (a) Can any improvement be made in the present system of forecast distribution?
 - (b) Should flags be displayed to represent forecasts for the current day?

(c) Can forecasts be given wider dissemination in rural districts, and what can be done to prove the value of forecasts in sections where they are not utilized?

(d) Should not forecasts be telegraphed to daily papers of small cities to avoid use of obsolete forecasts given in plate matter used in "make up"?

(e) Value of the logotype system.

5. Equipment and inspection of voluntary stations. Importance of instrument shelters.

6. Along what lines can special investigations be undertaken by State weather services with best results?

WEATHER SERVICE OFFICIALS AND OTHERS IN ATTENDANCE.

F. P. Chaffee, local forecast official, Montgomery, Ala.

F. H. Clark, local forecast official, Little Rock, Ark.

James A. Barwick, observer, Sacramento, Cal.

F. H. Brandenburg, observer, Denver, Colo.

A. J. Mitchell, observer, Jacksonville, Fla.

D. P. McCallum, observer, Idaho Falls, Idaho.

C. E. Linney, observer, Chicago, Ill.

Prof. H. A. Huston, Purdue University, Lafayette, Ind.

C. F. R. Wappenhans, local forecast official, Indianapolis, Ind.

G. M. Chappel, local forecast official, Des Moines, Iowa.

T. B. Jennings, observer, Topeka, Kans.

Frank Burke, local forecast official, Louisville, Ky.

R. E. Kerkam, local forecast official, New Orleans, La.

C. F. Schneider, observer, Lansing, Mich.

E. A. Beals, observer, Minneapolis, Minn.

R. J. Hyatt, local forecast official, Vicksburg, Miss.

A. E. Hackett, observer, Columbia, Mo.

Prof. G. D. Swezey, University of Nebraska, Lincoln, Nebr.

G. A. Loveland, observer, Lincoln, Nebr.

E. W. McGann, observer, New Brunswick, N. J.

H. B. Hersey, observer, Santa Fe, N. Mex.

R. M. Hardinge, observer, Ithaca, N. Y.

B. H. Bronson, observer, Bismarck, N. Dak.

H. W. Richardson, observer, Columbus, Ohio.

J. I. Widmeyer, observer, Oklahoma, Okla.

T. F. Townsend, observer, Philadelphia, Pa.

S. W. Glenn, local forecast official, Huron, S. Dak.

H. C. Bate, inspector, Nashville, Tenn.

I. M. Cline, local forecast official, Galveston, Tex.

G. N. Salisbury, observer, Seattle, Wash.

H. L. Ball, observer, Parkersburg, W. Va.

C. M. Strong, local forecast official, Milwaukee, Wis.

There were present the following-named voluntary observers and forecast displaymen:

B. F. Hole, Butlerville, Ind.

F. G. Erskine, Pleasant Ridge Park, Ky.

There were also present local forecast officials, H. C. Frankenfield and F. J. Walz, in charge of the Weather Bureau offices at St. Louis, Mo., and Davenport, Iowa, respectively.

The convention was called to order at 10.30 a. m., October 16, by the president, Maj. H. H. C. Dunwoody, who, after the call of the roll, addressed the meeting as follows:

ADDRESS OF THE PRESIDENT.

To one so long identified with the work of State weather service organizations, and who has watched with keen interest their progress from year to year, as has been the case with me, the greeting of so large a number of officials in charge of these organizations, with some of their voluntary collaborators, as are assembled on this occasion, is indeed a very great pleasure. I may properly state at the beginning of my remarks that it is a singular coincidence that the first convention of voluntary observers ever held assembled in this city thirteen years ago. And while the convention was called in November, 1882, a month later than now, the very dates on which it met are identical with those set for this convention, namely, the 16th and 17th. On that occasion we were honored by the presence of the chief executive of the State, Governor A. G. Porter, and my friend Captain Connor, whom I am glad to say is with us to-day. Interesting addresses on the subject of State weather services were delivered by both these distinguished gentlemen, and I also recall that several very able addresses on subjects pertinent to the State weather service were delivered by voluntary observers of Indiana. Among the latter who addressed the convention were Prof. Charles G. Boerner, of Vevay; Mr. William Dawson, of Spiceland; and Mr. John Chappelsmith, of New Harmony.

Having first suggested the organization of State weather services, as auxiliary to the National Weather Service, to General Hazen in 1881, I was sent by him from Washington to represent the Signal Service (at that time in charge of the Weather Service) at the voluntary observers' convention to which I have alluded. In the following year, under orders of the Chief Signal Officer, I made an official tour of a number of States for the purpose of conferring with the governors and other State authorities with a view to organizing State weather services, or creating an interest in such work. As the value of the State service was readily recognized by the officials with whom I consulted, I met with much encouragement, and during the following and succeeding years State weather services were organized with rapidity. The good work begun by the pioneer observers of Indiana has been carried on during the succeeding years with valuable results, the State to-day having a very efficient organization under the able management of Prof. H. A. Huston, of Purdue University, and his assistant, Mr. Wappenhans, local forecast official in charge of the Weather Bureau office in this city.

By 1892 the entire territory of the United States was covered by State weather service organizations. With the exception of the six New England States embraced in the territory of the New England weather service, and Maryland and Delaware, covered by the Maryland weather service, each State or Territory has its separate service.

During the latter part of 1885 the Chief Signal Officer issued a letter to the directors of the several State weather services in operation at that time suggesting a convention of directors. This suggestion was favorably received, and a convention was arranged for and held at the Smithsonian Institution in Washington, D. C., February 24 and 25, 1886. This was the last assemblage of State weather service directors until the summer of 1892, when, at the suggestion of Prof. Mark W. Harrington, Chief of the Weather Bureau, arrangements were made for a convention, which was held in Rochester, N. Y., August 15 and 16, in conjunction with the American Association for the Advancement of Science. At this second convention of State weather

service directors, at which eighteen services were represented, a permanent organization known as the American Association of State Weather Services was effected. Since then it has met annually, the two conventions immediately succeeding the first one being held in Chicago and Brooklyn. These gatherings of State weather service officials and their collaborators have resulted in great good, affording means for the exchange of views with respect to the methods of collecting and distributing weather and crop information. The published proceedings of the several conventions have been received with much interest, both by the officials engaged on State weather service work and the voluntary observers, weather crop correspondents and forecast displaymen who have been supplied with copies of the published reports. At the Brooklyn convention of last year it was very gratifying to the officials of the State Weather Services and myself to have in attendance several voluntary observers, and I am happy to state that we have with us to-day quite an attendance of voluntary observers, forecast displaymen, and crop correspondents of Indiana and neighboring States, indicating a growing interest in our work.

Having always been a sanguine believer in the value of these local services, it is with much gratification that I am able to say that the past year has been marked by especial activity in the several lines of work. A great improvement has been made in the character and form of a number of the monthly publications; but with respect to publications, the most marked improvement has been made in the form of the weather crop bulletins, which, with but a few exceptions, have been issued in printed form, being vastly more attractive and convenient than the milliliograph bulletin of former years.

The meteorological data furnished by monthly reports, giving summaries of the observations taken, are of incalculable advantage to engineers in charge of public works in making their calculations as to the capacity of sewers, reservoirs, etc. Some of the most striking illustrations of the data being collected and published by the New York State weather service were presented to the legislature of that State during its session last winter when an effort was made, on the score of economy, to cut off the appropriations for the State weather service.

The liberal policy of the honorable Secretary of Agriculture toward these services enables the Weather Bureau to do a great deal more now than in former years. During the year ending June 30, 1895, over 400 voluntary observers were furnished with the usual instrumental equipment of a voluntary station, and the number of stations now in operation has reached such proportions that the distance limit considered in the establishment of new stations has been reduced to 25 or 30 miles, the former limit having been fixed at 50 miles. The past year, in the work of distributing weather forecasts and special warnings, has been without precedent in the history of the Weather Bureau. Through the various State weather service organizations the daily forecasts or special warnings are sent to over 22,000 addresses, and with the arrangements now in hand the number is being rapidly increased. To the Post-Office Department, and especially to the present Postmaster-General, is the Weather Bureau greatly indebted for the hearty cooperation received in the distribution of forecasts by mail. The letter issued by Postmaster-General Wilson in May, 1895, and published in the Official Postal Guide for June, inviting postmasters throughout the country to lend their aid in the work of distribution was followed by many voluntary offers from postmasters, and a large number of distributing centers under the logotype system has been arranged for.

I recall the fact that less than two years ago I recommended to the honorable Secretary of Agriculture the expenditure of a small amount—I think it was about \$200—for the purchase of logotype outfits, and the practical and valuable feature of this suggestion was at once fully appreciated, and the amount requested for the experiment was freely authorized. The results fully justify the small expenditure, and to-day there are thousands of communities in this country which should thank Secretary Morton for the daily receipt of weather forecasts which previous to his administration it was impossible to secure.

Through State weather services and local organizations the benefits resulting from the Weather Bureau work has been more largely extended to the people during the past two years than in any like period in the past. The scientific work of the Bureau has been heartily supported and directed into proper lines of investigation, whereby the benefits of our service are being rapidly extended to agricultural communities.

The experience with the logotype system, which has now been in operation nearly two years, has been highly satisfactory, and it has proved the most convenient and economical means of distributing weather information ever tried by the Weather Bureau. With this system it is believed fully 90 per cent of the post-offices in the United States may eventually be reached by mail in time to make the forecast of benefit. In some States this work has not received the attention that the plan merits, but its success elsewhere proves that it can everywhere be made a most valuable means of communicating weather information. Directors of State weather services should, where not already done, fully acquaint themselves with the facilities of the cities and towns of their respective States, and correspond with the postmasters in towns having the best facilities for reaching outlying post-offices, with a view to establishing logotype distributing centers. What has been done in Ohio, where nearly 2,000 post-offices, or about 60 per cent of the entire number in the State are furnished with the forecasts by mail, can be done to greater or less extent in other States. This plan is especially commended to the attention of the directors of services who have, as yet, not developed this feature of the work as fully as they should.

In no year since the inauguration of the weather crop service have the bulletins, both State and national, been so largely sought for and closely watched as during the season just closed. Many of the State bulletins have been so enlarged as to attain proportions exceeding the national bulletin of a few years ago, while the national bulletin is now larger and more complete than in any previous year.

There is a great future for the Weather Bureau and its auxiliaries, the State weather services. The people are becoming more and more familiar with the work that is being accomplished for their benefit, and more fully realize its value. The Bureau is criticized for its shortcomings, and this is right; but when it accurately forecasts weather conditions thirty-six hours in advance at least eight times out of ten there is a good balance left to its credit after deducting the charges for failure. In my opinion, the public will never consent to an abridgment of the services now rendered by the Weather Bureau, and extension, rather than curtailment, will be the demand.

After consulting the directors of the various services, a list of topics for discussion has been prepared, and will furnish the programme of the convention. The discussion of these subjects and others that may be suggested can not but result in profit to those directing the operations of State weather services, and I hope that with this large attendance the work of this year's convention will prove even more valuable than the highly satisfactory results of previous conventions.

The journeys to these conventions to many are attended with great personal expense, and, in my opinion, it would be difficult to give stronger evidence of your fidelity to duty and interest in the work in which you are engaged than by your attendance. Some of you have arranged for brief vacations, well earned, after the convention adjourns, and it is my earnest wish that you will all have a profitable and pleasant experience. In conclusion, I desire to thank the members of the association for the honor they have conferred upon me in electing me president during the past three years.

At the conclusion of the address by the president he introduced the president of the board of trade, Mr. Gordon, who extended to the members of the convention an invitation to visit the rooms of the board and to a banquet.

DISCUSSION AT WEDNESDAY MORNING SESSION.

The PRESIDENT. I suggest that we take up now the regular programme. The first subject for discussion is, "How best to secure and retain the services of voluntary observers." I hope to hear from a good many of you on this topic. You are all anxious to please the voluntary observers, and it is important to increase the number of them, as upon the faithful work of the voluntary observers very largely depends the success of our organization. The subject is now open for discussion.

Mr. MITCHELL (Florida). I think this is one of the most important questions we have to contend with, that is, in some of the States. I mean to get good satisfaction from those who serve throughout the State. We are all aware that cheap service, as a rule, is poor service. While this is not generally the case in State weather services, we frequently find it so in all walks of life. As far as my State is concerned, I think that by enlarging the circulation of the publications of the different States—that is, those that have sufficient showing to issue a monthly publication—would be a very important feature to voluntary observers. Send them out over the country, and encourage publications from them, so far as the conditions will admit. I am satisfied that this will be a very important factor and give good satisfaction. I am satisfied that it will prove beneficial to the State of Florida, and I say also of other States.

Mr. BRONSON (North Dakota). Mr. President, do not all of the voluntary observers receive such publications now?

The PRESIDENT. I think a great majority of them do receive copies of such publications. I have always understood that they were furnished by the Bureau.

Mr. BRONSON (North Dakota). I think the best method of retaining the voluntary observers is to furnish them as promptly and as completely as possible with all information, whether taken from their own State or from other States. I would suggest as a matter of detail, in addition to that which has already been stated, that we have more or less correspondence with the voluntary observers. I think if it could be arranged we should furnish them with letter heads in order to establish communication between them and the directors. I think it would very greatly help along the line to furnish them with all necessary expenses—to put them in correspondence.

Mr. R. M. HARDINGE (New York). The State of New York has never had any difficulty in retaining the services of the voluntary observers after having once secured them, and in order to give them some little return for their services we have subscribed for a number of monthly journals and have distributed them from station to station, and we find that the observers are very much interested in them. The trouble is not at all in retaining their services, but there is trouble sometimes in getting rid of some of them. That is the most difficult part of our work. I suppose my experience in that line is no exception to many

others. Some of our observers want to take observations at any time—at any and all hours of the day; they make requests for barometers, hydrometers, and so on, and they wish to go into the work just the same as a man who is getting a good salary for the work. Of course we have to discourage such men, and in a way that will not be offensive to them. We have to let them down very easily. I think the voluntary observers are very much encouraged by being visited by the directors. It is a source of profit to them to be in touch with the directors and keep in touch with them. Write to them often. You have got to keep them interested in their work so that they will be interested in you, and naturally when they are interested in you they will become interested in the work you have for them to do. I have never had any difficulty at all.

Mr. BATE (Tennessee). It requires a great deal of knowledge of human nature, I might say, to work with voluntary observers. There are some of them who will be very much interested in the work for a few months, and then the novelty wears off and there begin to be gaps in their reports. Others will start out with almost any kind of an outfit and do good work. I have got some observers that have been taking observations with the same thermometers used in 1883, in use twelve years or twelve years and a half, and they have sent in their reports without a single break. Of course where you have observers like that there is no trouble at all. I think one of the best methods of getting good voluntary observers is to let them know that they are going to have a No. 1 outfit, and if they are interested enough in the work they will continue in it. This has been my experience, although I have not had very much during the past few years. It is a good idea to keep a voluntary observer impressed with the importance of his station as a factor in making the climatic history of his State.

Mr. HERSEY (New Mexico). I think the different conditions of the different States and Territories require entirely different methods of securing and retaining voluntary observers. Now, in New Mexico we have various kinds of population, a large part of it being of Spanish descent. Many of the Mexicans are not capable of attending to that kind of work, and so we have to rely on the American element. One of the surest ways of retaining observers that I have found is to become personally acquainted with them, if possible. I have never lost an observer that I wished to retain, by reason of being personally acquainted with him. They are interested in the work, and they do not like to drop it, for fear of wounding the feelings of their friends. In that Territory—New Mexico—some of our best observers are the railway station agents. I made arrangements with the superintendents of some of the main roads running through the Territory to instruct their agents to act as voluntary observers. They are usually a well-educated class of people and well fitted for such work. Some of our best reports come from them. By making their acquaintance personally and interesting

them you can almost always retain their services. This is one of the most valuable means that I have ever found.

Mr. JENNINGS (Kansas). In selecting voluntary observers I think you should first locate your town, and then visit that town. I do not think the scheme of recommendations from the postmasters will work very well. It depends altogether upon how the postmasters look at the question as to who they will recommend or suggest for the work. If you go to a town and talk the matter up, there is always some one who will be more or less interested in the subject, and then you can form a better estimate of your prospective observer. You can probably in this way get an observer that you can retain all the way through. In the eastern part of Kansas we have no difficulty at all in retaining the services of observers, especially if they are desirable ones. In the western part of the State it becomes much more difficult to keep them, simply from the fact that many men locate there and, after trying to get rich for a year or two and finding they can not so rapidly, they move away and locate somewhere else. In other words, the western part of the State is like the sands of the desert—carried around by the winds. After awhile you write to the postmaster to inquire why letters have not been answered, and he says in reply: "Why, that man has gone. He has left some things here which I think are for you." I would like, so far as I am concerned, to know of some good method of getting good observers stuck in the sand—get rooted out there. We have one in the southwestern part of the State, a civil engineer, and he would make a good observer anywhere. He wrote me at one time, suggesting that some one be appointed at Richfield, as it was a little nearer the railway and it would be easier to get the mail from there. I wrote back, saying that I would be very glad, indeed, to have some one at that place immediately, but that we would rather not lose his services. His work is nearly perfect, his reports come in regularly, and in his whole work there are not more than half a dozen errors in the whole year's time.

Now, as far as railroads are concerned, I am glad to hear somebody say a good word for the railroads. I think the Union Pacific Railroad has about forty or fifty stations between Brookville and Denver, and I corresponded with some of the people at those stations—with some of the voluntary observers along the line—in regard to their reports. I wrote to the superintendent of the road at Kansas City, asking him to inspect some of the stations. This was in February, 1887. Finally, I started out myself, and found that in a good many places the exposure of the thermometer was very poor. I found them usually in a little box 10 inches wide and probably 15 inches high, with a tin tube running out from the top for ventilation, and they would get very warm during the day. In many instances the boxes were placed on the north side of the buildings, but everyone knows that railroad buildings do not stand with the points of the compass. The railroads are very crooked and are built all around and over the country, and the

depots are built alongside of the track whichever way they happen to be. In some places the thermometers were exposed to the sun, and they had a temperature of 112° and 115°. One station reported very little rainfall, and at the next station there was a tremendous rainfall, the observer reporting from 3 to 4 inches every time it rained. He had his rain gauge under the rain spout that carried the water off the depot. He said his instructions were to catch the rain water. An agent asked me one time, "How much rain do you think we had here last night?" I replied probably 0.76. "Well," he said, "it is pretty nearly an inch." It is my experience that the best method of securing observers is to pick out your town first where you want one located, and then go there in person and get acquainted with the business men, and state your case to them. I usually take with me a copy of the National Review and show it to them. By the way, our State Review has not been printed this year because of a little difficulty between the State board of agriculture and the printing commissioners. I take this National Review to them and say to them, "Now, here is a bulletin that is printed every month, twelve times a year, and is sent all over the world. People don't know that you have a town here, but they do know that there is a town of McPherson next to you over there because the name appears in this list, and you ought to have pride enough about you to advertise this town all over the world. If you can get some man to take charge of a set of instruments which the Government will provide, why you can get your town advertised for nothing twelve times a year." There has sometimes been considerable expense attached to the reaching of these towns, as they were not situated by the railroads. The bicycles are of very great advantage, because you can strike across the country and save time and expense. I think the weather bulletin when printed and sent to the observers goes a long way in retaining their services. A great many publications are exchanged. You have all heard of the Hay Trade Journal, published in New York, and the American Swineherd, published in Chicago, and I might mention a good many others. They are of no particular use to our offices, but we distribute them to parts of the State where they are interested in hay and in swine and so on, and we find they are very greatly interested in them.

The PRESIDENT. We have with us a gentleman who has had a great deal of experience in securing and retaining voluntary observers, and he probably has more information on the subject than most of us. I shall extend an invitation to him to make any remarks upon this subject that he may wish, or upon kindred subjects. We would like to hear from the Chief of the Weather Bureau.

Professor MOORE (Chief of the Weather Bureau). I do not know whether I have lost my membership in this organization or not by being called to a higher position; but anyway, my interest is with you and my heart is with you. I spent three years actively in the State

service work, and I can say that I have never had cause to regret my connection with this important branch of the Weather Bureau. Nothing will ever cause me to disparage the work done by the State weather services, but rather it is my desire to see it extended, and become more comprehensive in its scope.

I hardly think, Mr. President, that I shall talk much on the subject you have given me. I am too full of something else. I am aware that you are all members of the Federal service and that you are all officials of the United States Weather Bureau, as well as directors of State weather services. Now, the work of your State weather services during the past year or two has been so admirably outlined and referred to by your able president that it is not my purpose to enter into that at all, although I heartily concur in everything he has said. I would rather speak to you of the attitude of the Department of Agriculture to the Weather Bureau as a whole, than as a State weather service system. I wish to speak of the policy of the honorable Secretary of Agriculture toward the Bureau. In calling me to the position I now hold, he informed me that I should enter the office free and untrammelled; that I should enter into it with the single and only purpose of making it the greatest weather bureau in the world, and that to accomplish that end there was but one policy to pursue, and that was to recognize every man for his merit, to make recommendations for promotion entirely upon the record of the men, without regard to political considerations and without regard to religious affiliations—that only the merit of each worker should be considered. I have tried to impress upon all the fact that I shall not waver in my duty, or allow other than honorable motives to influence me in my recommendations. I can not make this point too strong, for our whole success and the whole development of the Bureau depends upon our making it a merit system, pure and simple. Within the past ninety days there has been a professor of meteorology selected, and there has been a weather forecaster selected; in both cases they were men who had made especially high averages in their work. The one selected for professor made the highest average in forecast work, during the past year, of all officers at Washington. He was selected accordingly. The national forecaster was selected because in recent competitive examinations he made the second highest place. In both cases they were selected for their ability and devotion to duty. Economy has been rigidly practiced in the Bureau in cutting off all unnecessary compilation of data, as I presume you have all noticed by the recent orders which have gone out to you. This has enabled us to dispense with the services of some few workers who have not been up to the standard of efficiency, and has also enabled us materially to advance in salary seventy-eight of the deserving men of our service. Not only has the letter of civil service been observed, but the spirit has been steadily carried forward.

I know that your deliberations here as State weather service directors

are for the good of the Weather Bureau, and your devotion to this cause is certainly admirable, coming here each year as you do at your own expense and each year growing and increasing in knowledge. This is the finest presentation the State weather service men have ever made, and I hope that your deliberations will result in pleasure to yourselves personally as well as in profit to the Bureau.

Mr. CHAFFEE (Alabama). Before taking up the next question, I want to say that I agree with the director from Florida that this question we have been discussing is one of the most important we have to contend with. Now, as to the best means of obtaining voluntary observers, I would say nothing; that point has already been sufficiently discussed. But one of the best means of retaining them that I know of is to let them know that their work is being used for the benefit of their State. I always impress that fact upon them. When I find that they are losing interest, I write them and again impress that fact upon their minds. It is one of the most telling features, to my mind, to let them know that their reports are being used for the benefit of their State in advertising to prospective immigrants and investors the climatic resources and advantages of their section.

Mr. MCGANN (New Jersey). I think one of the best and surest methods of retaining the interest and the services of the voluntary observers is to insure a prompt and accurate publication of the essential points of their reports. Men generally like to see their names in print. There is not one of us that does not. I think that method helps the men more than anything else. After we have their reports, print them and let them see that they are printed and that we have had them printed accurately. Print special remarks from their stations which they make. They like to see them. I think it appeals almost directly to each individual, and is a matter of the greatest importance to them. As to the method of securing observers, in the Central States at least, there is a growing organization which I believe will help us a great deal if we will use them, and that is the farmers of the different States. From among the farmers, I believe we can secure a good many voluntary observers of the very best type. The men generally live on farms, which would afford a reasonably good exposure for instruments, and they would take a daily record. They are permanent residents, and they are men, as we all know, who do their work well. They are always at home, always on hand; they are men who realize that the meteorological observations are of the utmost importance to them and to their crops and to their farms in general. As the question of drainage is being discussed more and more, the question of rainfall also becomes more important to the farmers. There is no doubt in my mind that from these institutes voluntary observers could be obtained who would serve almost continuously; they would make permanent and valuable observers, it seems to me, and it is the most promising outlook I have yet seen in our State.

Mr. SCHNEIDER (Michigan). I have been very successful in placing voluntary observers in the care of fire departments in towns large enough to afford a fire department, or in towns where there is a system of waterworks where there is a pumping station day and night. I have placed many voluntary observers very satisfactorily in this way. This, of course, pertains only to the larger cities, but it becomes permanent, and is something that lasts for all time. I always equip my observers with a good set of instruments and see that there is good shelter. They are usually a very intelligent set of people, and they carry on this work very successfully, as they are always on hand. Another point to bring up is the payment of voluntary observers. In our State, four or five years ago, under the régime of Mr. Conger, we paid our voluntary observers from an appropriation made by the State \$1 a month, and it is wonderful how much you can do with the voluntary observers if you make their work a matter of dollars and cents. Of course I know that in this voluntary observer work you have got to treat them cordially and furnish them with all your publications, etc., before they will sometimes resume their duties, but in a matter of dollars there is no difficulty in making a permanent affair out of it, and it is my object to make them as permanent as possible.

Dr. I. M. CLINE (Texas). Over the eastern half of the State we can get more observers than we desire. Some of them are railroad men, and they make good observers. We do not have the advantage of many railroads in the western portion of the State where observers are most needed, and hence can not draw on them for observers. We manage to work up considerable interest among our voluntary observers by occasional visits to fairs, farmers' institutes, etc., where we meet voluntary observers and talk with them. Another feature which we are putting forward in Texas, and one which interests the voluntary observers and demonstrates to them the practical value of their work to the State, is the issue of special bulletins devoted to climatology, agriculture, horticulture, etc., local and general. This does more to enliven an interest in the work than anything I know of. We have no trouble in securing and retaining voluntary observers over the eastern portion of the State, but in the western portion we have a number of counties sparsely inhabited, and those who inhabit some of them are, as a rule, herders, who have no personal interests. Of course it is very difficult to reach those counties. The land is owned by nonresidents; but when we can reach them they generally arrange to have some one in their employ take hold of the work, but even then we can not always find one who can keep up the records; and as for farmers' institutes and such organizations, we have none in west Texas. In that part of the State the question of irrigation is a great one, and our people want all the statistics of rainfall that they can possibly get; and I find that wherever there are men who have interests and are properly located they gladly take hold of this work in their section, realizing that it is to their own benefit.

Mr. GLENN (South Dakota). Voluntary observers are doing a great work and I would rather have them interested and earnest in that work. We should lose no opportunity of showing our appreciation of what they do and what they have done. We are earnest and sincere in our efforts to build up State weather services, and by infusing this spirit into the observers, we not only get better service but are more liable to retain them. This policy has been successful in my State. The receipt of every Form 1009 and 1067 is immediately acknowledged in a courteous letter to the observer, and he is thanked for the report and his promptness in rendering it. My greatest cause of loss in voluntary observers has been due to their departure from the State.

Mr. SAGE (Iowa). Mr. President, there are observers and observers; good observers are born, not made. Now, as to the observers in our State. There is no trouble at all in getting them, but the trouble is in the matter of selection; not to find a man, but to find the right man. There are more men offering their services in Iowa than we can begin to supply or equip with instruments. I think the thing for the Government to do is to enlarge its appropriation in order to get instruments that can be utilized to good advantage. I believe that we should be more liberal in supplying instruments, and that is the greatest difficulty we have in Iowa—the lack of funds for this purpose. There is another point I would like to speak about—the railroads. They become intensely interested in this work, and appreciate fully the value of this service to their own interests. I have had letters from presidents of roads, and from superintendents of construction, and from chief engineers, asking about this matter of rainfall. They want the information for the construction of their culverts and bridges. And I have also had conversation with some of the different men in regard to furnishing rain gauges at the stations. They say that they will give us free telegraphic messages at all times if we will furnish the instruments. This is what we ought to do. I think, however, the Government of the United States ought to do a part in this matter, and the people in Iowa are willing to go more than half way. We can very greatly enhance the value of this service by local cooperation, by utilizing all local sources of information. There is nothing that can be done in this world without cooperation.

Dr. R. J. HYATT (Mississippi). Mr. President, I have found that one of the best means of securing voluntary observers is by selecting them from the large number of crop correspondents throughout the State. Any man who will render a good crop report will also make an accurate voluntary observer. I have a great many excellent crop reporters, some of them having instruments of their own, and from this source the number of voluntary observers can be increased very satisfactorily. I have had no trouble in retaining the services of voluntary observers after they are once well started and instructed in the work of the service. They take a pride in the publication of their reports,

Mr. STRONG (Wisconsin). On the subject of procuring or retaining the services of voluntary observers, I think there is nothing so effectual as a frequent inspection of their work; to visit them and become acquainted with them. I find this to be the case in Wisconsin, where the men take the greatest interest in the welfare of their towns, and I find that they are willing to contribute their time for the benefit of their immediate region.

Mr. MCGANN (New Jersey). Speaking of a small remuneration, say \$1, I don't believe that would amount to anything with the voluntary observers. Without it, I think the voluntary observer has an interest in the welfare and development of his country, and that he is giving his services as a public good for the public benefit, and the way to retain him is to visit him and become acquainted with him, and make him feel that his services are of value to you. Of course this is difficult for the directors to do at their own expense; we can hardly expect it of them, and we can not see our way clear to allow them Government transportation as yet. But I do want to see the day when an allowance can be made for this purpose—enabling the directors to visit and inspect the stations of their voluntary observers without pecuniary loss to themselves.

The PRESIDENT. Now, gentlemen, if there is nothing further on this subject, and as it is half past 11, we will adjourn for the purpose of visiting the board of trade in their rooms. They have invited us to do so. We will be on hand again at 2 o'clock.

The convention then adjourned until 2 o'clock p.m.

DISCUSSION AT WEDNESDAY AFTERNOON SESSION.

The PRESIDENT. I have just received the following telegram from Mr. Pague:

PORTLAND, OREG., October 16, 1895.

The President American Association of State Weather Services, Indianapolis, Ind.

My compliments to the members of the convention. Wish you all unbounded success in all endeavors, and trust the meeting may be beneficial and enjoyable. Regret my inability to be with you. The people of Oregon would like to have you meet in Portland next year.

B. S. PAGUE.

We will now proceed with the next subject on the programme, which is No. 2, and is one of the most important with which we are identified: "What can be done to improve weekly weather crop bulletins and increase their value?" I think it will be well for the members of the association in discussing this subject to make their remarks applicable to their localities, and thus give the members of the Association more detailed information. These bulletins afford an excellent means for studying the interests of the several sections that may be benefited or protected through a foreknowledge of weather changes, and I think it would be well for everyone charged with the duty of making forecasts to make a careful study of the interests that may be served in each locality, so as to be fully informed concerning the crops liable to injury

from such changes. I find the benefits resulting from the forecasts largely depend upon the understanding of the forecast official as to the special interests the forecasts may serve; therefore, in discussing these questions, we must remember that much responsibility rests upon the man who prepares the forecast. I would like to hear from some of the gentlemen on the subject, "What can be done to improve the weather crop bulletin and increase its value?"

Mr. CHAFFEE (Alabama). I do not wish to interject anything foreign to the topic under discussion, but I would like to say here, in the interests of the rice growers of southeast Alabama, and the same may be said for the lowland rice planters of the Carolinas that warnings of high winds are of vital interest to lowland rice planters at that stage of the crop when it has nearly matured. The heads of rice are then full and nearly bursting; any high wind will switch about and shake out a large amount of rice on the ground. Now, those planters engaged in wet culture of rice, all of whom have their fields dyked around, can upon receiving warnings of high winds open their sluice gates, let in the water, and flood the rice nearly up to the heads; the water holds the stalks steady and prevents damage by wind. When the danger is past the water is withdrawn. The water does not injure the rice; and I know of several cases where the action I have mentioned has saved a rice crop.

Professor SWEZEY (Nebraska). Mr. Chairman, I would like to say a word about the value and appreciation of the maps. Now, for three years we have published a map giving the actual amount of rainfall. These maps have been so highly appreciated in our State that it seems to me it ought to be taken up in every State. I think we are justified in saying that the map is appreciated, inasmuch as it is copied by the Lincoln and Omaha dailies, by the Nebraska Farmer, our leading agricultural weekly, and by the Lincoln Newspaper Union, by which it is sent out widely to the country papers.

As to the cost of the outfit, of course that depends upon what you have to buy. It consists of two rather heavy iron plates, with metal bars running lengthwise between them, and these are clamped together. The blank map answers the ordinary purpose.

The PRESIDENT. I have received a recent communication or suggestion which I think can be utilized by the members of this association; at any rate, I am anxious to impress it upon the members of the association. The suggestion is this: That the newspapers have been criticizing the local forecasts, and that we ought to seek opportunities to give the papers some important news. Say to the reporters, "I have got a little item here which will interest you and that will also be of interest to your paper and to your locality." Tell the reporters to call around occasionally; that you can give them something which will be of interest. If we do this the papers will certainly be more lenient in their criticism on the Bureau. Give them something that they consider of interest and value and that will benefit them to publish. Before we

go any further on this subject, there is a gentleman here who has the honor of having first called a convention of State weather service men, Mr. J. B. Connor, of Indiana. He was the head of the State weather service thirteen years ago, and he conceived the idea of calling his voluntary observers together in convention. He is still interested in this work, and he is also the owner and publisher of the *Indiana Farmer*, which publishes the crop bulletin of this State, and which spreads information throughout this as well as neighboring States. I would like to have him give his views on the subject of voluntary service to this convention for a few moments.

Mr. J. B. CONNOR (Indiana). I have always been very much interested, as our president says, in the work of State weather services. It was at the instance of Governor Porter, of this State, that the service was organized in Indiana, when I was the chief of the bureau of statistics, and I believe our first convention was called in 1882. I had heard a great deal on the subject of the State weather service, but it was a new kind of work for me. To secure a respectable number of stations in the State, if you will permit me to go on with this suggestion, I prepared a circular and sent it out to the various people whose names I had obtained who were not in our work, and many expressed their willingness to take hold of the work, and it was in this way that the voluntary observers were secured. I was only connected with this service for two years, or perhaps less than two years, and as my successor as chief of the bureau of statistics seemed to have no appreciation of the work, it was afterwards transferred to the Agricultural College of the State, which was well fitted up, and from which the State is gaining very much advantage, for certainly the service has become very efficient and very valuable to the State. Well, it was in 1882, I think, that the first meteorological convention was held that was ever held in the United States. At that convention we secured the attendance of nearly all of the voluntary observers we had obtained, and the convention interested them very much. It was as a result of that kind of work that the interest was kept up in the weather service. I am glad to look you all in the face and to see so many States represented here. Certainly you are engaged in a very important and a very great work; but it is a work that is not fully appreciated as yet.

I heard some of the discussions this morning about retaining and securing voluntary observers. That is a very important question, and a question that the public does not yet have full appreciation of. We are all trying to live a year in a month. That is our trouble. We live too fast. We want to know it all from the start to finish at once, and we are trying to do a great deal more than we are able to do; yet a great deal of work is being done, and the data that has been collected by the State weather services all over the country will sometime, not many years hence, vindicate the splendid work you are doing.

Mr. JENNINGS (Kausas). In regard to this map of which Professor

Swezey has spoken, I want to say that it has cost me 60 cents a week all the season through. I, for one, want to thank Professor Swezey for the explanations he has given us. We started out with using a plate map; we first got the idea from Nebraska. The Kansas Farmer printed it, and it was a great success. We heard all through the season how that map was appreciated, but at the close of the season, when we stopped it, the Kansas Farmer people came to us and asked us if we were going to stop putting that map in the paper. They asked if we stopped the weekly reports, why couldn't we give them a monthly map. Now, they are going to publish a monthly map at their own expense, showing the distribution of the rainfall all over the State. The Kansas Farmer told us that they never dreamed that the subject had such a strong hold upon the people—upon their subscribers—until we cut off printing that map, and then the letters came pouring in. They are now going to publish a monthly map, which came out for the first time, I believe, in September. We can get perhaps 200 of these papers free, and distribute them over the State, and when they are in the hands of the various State weather service men we can increase the value of the weekly bulletin.

Mr. SAGE (Iowa). When rains are very local in character I do not see how it is possible, on such a small chart, to include the rainfall of places which are so close together. This is the fault I find with the method of illustrating by charts.

Dr. I. M. CLINE (Texas). Speaking about the people getting interested in the precipitation charts, I wish to say that we began the issue of these maps in colors in 1891. The value of anything is to be judged by the extent to which it is used by those interested. The demand for this chart became so great that the labor involved in the preparation of a sufficient number of them necessitated a change to some method which would require less labor. As an illustration of the practical value of these charts in Texas, a cotton factor in Galveston, who advances large sums of money each year on the crops of farmers in various parts of the State from time to time while the crop is making, says that he takes those charts and hangs them on the wall of his office, and whenever a planter wants money on his crop he can, by a look at the rain charts, determine just how much money it will be safe to advance on the crop. This is a single case; I could cite a number. Our people would not do without this chart. In order to enable me to issue the chalk-plate map it was necessary to obtain the assistance of the newspapers. When I first commenced the issue of the chart, as already stated, I could not convince them of its importance, but they eventually recognized its valuable features, and in last June the Galveston and Dallas Daily News, and also the Semi-Weekly News, which is issued on the day of issue of our bulletin, commenced the publication of the chart, which gives it a circulation of 100,000 on the day following its issue, and mostly in small villages and among farmers where it

is of greatest value. The chart has already become such a prominent feature of the bulletin that every daily paper in the State desires to publish it. A paper of some 20,000 or 30,000 circulation, published 50 miles from Galveston, sent a man down to see me last Friday to see if arrangements could not be made which would enable them to publish the chart. I advised them that I would furnish them with a miniature map of Texas ready to draw from. We are at no expense for this chart except the labor in drawing it, which is contributed by myself or one of my assistants. The papers give us the base plates, make the casts, and get them ready for us.

Mr. MCGANN (New Jersey). I would like to ask the question whether it is considered the omission of the reports of crop correspondents would detract in any way from the value of the bulletin, or whether it is considered advisable to publish a bulletin, as a great many of the services do, without the notes from their correspondents?

Mr. SAGE (Iowa). If I had my choice between the two—as between the bulletin that contained the reports condensed, as the correspondents gave them, or the one that contained the editorial summary—I would say leave out the summary every time. The people want reports that they can study as to their own and other localities. These inform them of the condition of crops in the agricultural districts, of the live stock and the diseases of live stock, and so on, and the people are continually looking for some reference to those things in the weekly bulletins. They want specific information and not mere generalities.

Mr. MCGANN (New Jersey). I have advocated at previous meetings the advisability of all weekly crop bulletins being published with reference to what the farmers themselves do and say relative to the crops. If you do not publish these items, then the weekly bulletin is of little value to them. Its great value is in what the farmers themselves say about the crops. This is so as far as my State is concerned. Of course I do not want to force any of my ideas upon you, because the interests of the different States are so diversified that what would suit one State might not suit another.

Mr. TOWNSEND (Pennsylvania). I want to say just a word in regard to the illustration of weekly rainfall by map shading. I think it is misleading, particularly where the showers are local in character, as they generally are in my own State during the summer months. In connection with this subject, in giving the amount of rainfall I think we lose sight of one very important factor in failing to give the character of the rainfall, whether heavy or light. This is particularly important in hilly countries like Pennsylvania, where the light rains are absorbed by the soil while the heavy downpours run off rapidly to the adjacent streams. The duration of each rainfall should be reported.

Mr. HERSEY (New Mexico). In regard to graphically illustrating rainfall, I do not think the plan well adapted to New Mexico for weekly reports, and for monthly reports it can be used to little advantage.

Frequently there will be no more than one or two stations reporting for a whole week, possibly only one station, and it would report from half to three-quarters of an inch—just local showers, it may be, and so it would really amount to nothing more than putting the figures on a blank map in many cases. I think it should be left to the directors of the different services what they should use and what they should not. I believe it is a good plan to use extracts from the reports of the voluntary observers in as nearly their own language as possible. The most of the weekly papers of New Mexico contain the remarks of the observers and their authority for their remarks. I believe this plan is of more interest to the public, and it also keeps up the interest of the observer in his work.

Mr. MITCHELL (Florida). Apropos of the rainfall relative to Florida, I feel sure that the chart would be misleading, and substantiate the theory by citing the case of two rainfall stations that I think are about a mile and a half apart. The voluntary observer obtains the official reports from the experimental station there, where the rainfall is kept. Now, it has been my observation during the past five or six months that within distances of a mile and a mile and a half there are many times 2 or 3 inches difference in the rainfall for these two places. My attention has been attracted to marked difference in stations closely located. During the summer months in Florida, sometimes it rains forty days and forty nights not half a mile from the coast; consequently, I think the insertion of the rainfall on blank maps at specified stations will meet all demands and will be more faithful to the exact meteorological conditions.

Mr. CHAFFEE (Alabama). Regardless of the question as to how the rainfall data should be published, on which there seems to be some diversity of opinion, and coming back to the question as to whether selected voluntary observers should not be given authority to telegraph State centers reports of rainfall, I would like to say in the interest of the cotton industry of Alabama, which is one of the greatest cotton growing States, that I am sure I could make good use of such telegraphic reports; they would enable me to issue more exact information as to rainfall throughout the State. I am sure such information would be very much appreciated in my section.

Mr. BATE (Tennessee). The character of the rains in our State is mostly very local. I have looked out of my window and seen a fine shower right across the river and not a drop of water in my rain gauge; and then, on the other hand, we have had showers at Nashville and the surrounding country has not had a drop. The best way I think is to use the figures.

Professor SWEZEY (Nebraska). That is very true, if you have a limited number of stations. As it is in Nebraska we could not begin to write those figures on these maps; they would cover the whole map, and of course if you were to put in the location of the rains every time it would be misleading; the maps would not hold that number of names, as you have but very little space.

The PRESIDENT. Mr. Berry has had a great deal of experience on the subject of rainfall and may possibly have something to say to us.

Mr. BERRY (of the Weather Bureau). Mr. President, while admitting that any method of graphic illustration is open to objection, I still believe that the scale of shading adopted by the national Bureau for the Monthly Weather Review and Weather Crop Bulletin affords a very satisfactory means of exhibiting the distribution of rainfall. Precipitation measurements are generally recorded in inches and hundredths, and with any considerable number of reports the figures would appear so crowded on a map of small scale as to render it impossible to obtain at a glance an intelligent idea as to the general distribution of rainfall which can be so readily seen on shaded maps. The accuracy of the charts of course depends upon the number and reliability of reports and the competency of the person preparing the map. In our best books on meteorology and in current publications on that subject graphic illustrations are extensively employed, and I do not think that we can do better than to continue the use of shades for representing rainfall distribution.

Dr. HYATT (Mississippi). While we have never published the rainfall chart of my State, I think it is important. The great objection is the expense connected with it. I have found in my experience that the publication of the remarks and names of correspondents has been of great benefit and interest, and I have noticed that the reports are rendered more promptly and more numerous than before on account of these publications.

Mr. MITCHELL (Florida). With reference to the advisability of selected stations telegraphing rainfall for the weekly crop bulletin, it strikes me that this is a question deserving more than passing notice. Many stations in my State have to mail reports a little in advance, and subsequent to mailing it is not infrequent that a general and refreshing rain visits the county, and under such circumstances to use the data on the weekly card (which might indicate need of moisture) would be misleading and do harm. As it is, I keep close watch of press telegrams, and with the general weather conditions indicated on the chart am enabled to represent matters very satisfactorily. However, a few isolated though important stations could be selected to telegraph rainfall with much advantage.

The PRESIDENT. We will now proceed with the third subject, "Monthly publications."

Mr. CHAFFEE (Alabama). As to the best form of publication, which is an important subject, I wish to say that it was my idea to have a double sheet like that prepared at the office of the Bureau, and have them printed in great numbers. The cost would be but little. One page would be enough for all of the stations, with the headings printed in. I think that it is important that we should have something that we can preserve for reference if necessary. The two sheets can be bound together. I have used such sheets for some time, and they embrace

everything that is found in the monthly reports. We ought to have these publications in some form in which we can preserve them.

Mr. MCGANN (New Jersey). It may be useful to some of the gentlemen here who did not attend the convention at Brooklyn last year to know something about the method discussed there relative to publications of the experimental stations. The director of the State experimental station of New York was asked to express his opinion relative to the value of publications that were being sent out by him in that State. He wrote to the secretary of the agricultural board that he thought so highly of the work that was being done that if the appropriation was increased they would carry it on. Now, it may be, as perhaps one of the gentlemen here said, that if there was an appropriation for this work more of us might undertake to publish the monthly bulletin.

Mr. J. I. WIDMEYER (Oklahoma). We have also an experimental station in Oklahoma, which is located in the northern part of the Territory. The director of that station offered me \$600 if I would move my station up to his place and prepare the meteorological data for them to print. I have always been sorry that I was not so situated that I could avail myself of the offer, because it would have been of great benefit to the Territory. Our publication is about the size of that used in Texas, and on the first page we have the names of the voluntary observers, which is used for the benefit of the observers themselves. We get their remarks as far as we can, but the chief feature of our bulletin is the manner in which the rainfall is presented. We have it so that we get it up in the shortest form possible, as we find this is the most convenient for reference. There are so many people coming in from day to day, and they all want to know the amount of rainfall. We publish this bulletin in Oklahoma without any cost to the national Bureau.

Dr. I. M. CLINE (Texas). I think the bulletin we issue is about the uniform size, or standard size, for such publications, and contains the data most desired for file and reference, namely, the daily maximum and minimum temperatures and the daily precipitation. While our bulletin is printed, it is not impracticable for those who prepare their bulletins by some duplicating process to make them of the same dimensions (although they may contain different data if desired) so that the bulletins of the various State services can be bound together. The question of prompt issue of these bulletins is also another important one, and I think we should give much attention to it.

After Dr. Cline's remarks the convention adjourned until 10 a. m., October 17.

DISCUSSION AT THURSDAY MORNING SESSION.

The PRESIDENT. The convention will now come to order, and we will proceed with the fourth subject of our programme, "distribution of

forecasts." The members of the association are at liberty to discuss any one of the heads given.

Mr. TOWNSEND (Pennsylvania). This is a matter I have had under consideration for some time, because I believe the use of flags will be greatly improved upon; therefore I have submitted to this convention, in the simplest form in which it can be constructed, this semaphore, which I wish to explain. [The semaphore was here exhibited.]

The "Semaphore weather signal" consists of a weather vane and disc so connected by an arm that the disc can be revolved and retained in any desired position.

By it eight distinct combinations can be given that are determined by relative positions of the disc to the vane, and they are easily distinguished and understood, because they are suggestive of the weather conditions—higher, lower, stationary temperature, or a cold wave, with fair weather, rain, or snow.

As a combination signal its visibility is greater than that of flags, cones, or drums, because the element of position only is all that is necessary to determine to understand the combination.

It is distinctive in character, simple in construction, easy to manipulate, and not liable to get out of order.

In point of durability and economy it will outlast several sets of flags at a much less cost.

By the use of electric lights it can readily be made a night signal.

Question. What would be the cost of such an instrument?

Mr. TOWNSEND (Pennsylvania). Well, that of course depends upon how it is constructed; but they can probably be made for about \$2. It is so simple in construction that most anybody could make one with a little effort. I do not claim it is in any way superior or inferior to flags, but I think it has advantages that flags have not.

Mr. SALISBURY (Washington). May I ask if the semaphore is supposed to assume a certain position, or if there is a mechanism for the purpose of revolving it horizontally?

Mr. TOWNSEND (Pennsylvania). There is no mechanism for revolving it horizontally.

Mr. SALISBURY (Washington). I do not wish to speak discouragingly of this design of semaphore, which has evidently taken much thought and has admirable points, but as I understand its construction I will say that I do not think it will accomplish the purpose of indicating weather signals as well as flags, for the following reasons: The semaphore is not well adapted for indicating signals to points directly before or behind it, as on railroads. When behind it the signal is reversed, which is a disadvantage. The plane of greatest visibility is at right angles to the plane of the semaphore, and the visibility decreases as the angle decreases, until at zero, or 180°, the signal becomes practically indistinguishable, as is the case with any flat object viewed on edge. This I regard as a fundamental objection. No, I do not think

flags have this defect to the same degree. It is hard to choose a position from which either the form or the color of the flags can not be determined, no matter what the wind direction. I am not a defender of the flag system, but if a change is made it should be to something better.

Professor MOORE (Chief of Weather Bureau). I think Mr. Salisbury has stated a very serious objection to the semaphore.

Mr. CHAFFEE (Alabama). It seems to me the objection as to the visibility, or rather the invisibility, of the semaphore signal could be easily remedied by having the tail of the semaphore composed of two pieces of plank, to be spread out at the outer ends like the tail of a wind vane; then have a ball in place of a disc, as now shown; this ball could pass between the two pieces of the tail when moved above or below it; such an arrangement would make the signal thoroughly visible from all directions.

Mr. MITCHELL (Florida). I believe almost any change would be an improvement on the present system. Flags soon become soiled and worn, and after the lapse of, say a year, are unsightly. In the interior of Florida there are many days when the flags indicate nothing—not being seen, due to lack of wind.

Mr. TOWNSEND (Pennsylvania). Whatever may be the value of any work done by the Weather Bureau with the general public none ranks in importance with that of forecasting. This is daily demonstrated by the desire manifested to obtain the forecasts. Years of constant and well-directed effort has developed the present extensive system of distribution, which is highly creditable to the Bureau, but the limit has not been reached, and the experience of those engaged in State service work should enable them in replying to questions *b* and *c* of the programme to make practical suggestions in the line of improvement. I submit the following for consideration:

(*b*) Should flags be displayed to represent forecasts for the current day?

I answer, yes; but all displays should be so made that the public will know exactly what time is covered by the forecast. I find under the present system of display a lamentable lack of definiteness in their interpretation, and to remedy this defect I suggest that all displays from early morning to 1 p. m. shall be a forecast of the weather conditions for the current day, and all displays from 1 p. m. to dark shall be for the ensuing day.

(*c*) Can forecasts be given wider dissemination in rural districts, and what can be done to prove the value of forecasts in sections where they are not utilized?

Districts remote from mail and telegraphic facilities can only be reached by a concerted system of signal duplication. This is entirely practicable where the residents at proper distances from each other will erect and display signals similar to the one that should be copied. By properly organized efforts on the part of those who desire to avail

themselves of the benefits to be derived from the daily information furnished by the Bureau, there is practically no limit to the territory that can be rapidly covered by information signals at a small cost and with very little labor.

Farmers should willingly bear a part of the voluntary service that is daily performed for their benefit, particularly when the information to be transmitted is of practical value to them and their neighbors located so remote from telegraphic and mail facilities that their district can not be reached with the desired information without their cooperation. To insure correct and prompt displays at the distributing center the display man at that point should be paid a small salary.

For such displays the semaphore signal is undoubtedly better than flags, because of its greater visibility and lack of dependence on strong winds for its proper exposure. Besides, when once constructed it should last a long time without sensible change and always be ready for immediate use. Its ease of manipulation enables almost anyone to make the necessary changes in the combinations.

In answer to the last paragraph in (c), a little experience will prove the value of the forecasts where they are not now utilized.

(d) Should not forecasts be telegraphed to daily papers of small cities to avoid use of obsolete forecasts given in plate matter used in make-up?

Yes. As daily papers are necessarily dependent on large subscription lists and good mail facilities for their support, it necessarily follows that they are among the best and cheapest means for the prompt dissemination of forecasts.

(e) Value of the logotype system.

This is an economical manner of distribution, and in most cases has been found satisfactory.

Professor HUSTON (Indiana). I think it is a matter of some importance to know for what purpose the forecasts are used. I was very much surprised to learn this summer that in Fayette County, this State, which is about 60 miles from here, there were extensive tobacco crops being raised which represented a high monetary value. I happened to be down there in the fall, and I asked a man who owned one of the large crops if they received any warnings or forecasts there, and he said no. I told him at that time that he had better get his tobacco in then as quickly as possible; and when later I was down there again I found that he had taken my advice, and that he had it all cut and in the house. I think we should use much care in finding out what new crops are being raised. I know of extensive pickle industries going up, and also many others recently coming in which are more than usually sensitive to unusual weather conditions, and I believe it is no small part of the business of the weather service to keep posted on these new things. Of course when a State is in the extreme north or the extreme south that it is not so easy, and can not so easily be kept track of; but the central part is where changes occur quite rapidly in the system of

agriculture, and that of course means a change in the nature of the forecasts that are to be made for this section.

Mr. FRANK BURKE (Kentucky). In regard to the tobacco crop in our State, ordinarily we do not have a frost that will do any damage to it once in four or five years. The crops as a rule are nearly housed by the 15th of September; that can almost be depended upon. I think the damage that was reported this year was largely individual and not at all general; there may have been some certain localities where the crop, owing to unfavorable conditions, was set out late, and it was damaged. But I had reports from some reliable correspondents and voluntary observers saying that there was in their section of the State, southern half, not more than 5 per cent of damage to the tobacco, and I was also informed by the secretary of the tobacco board of trade that this was so, and his statements corroborated those of the correspondents. The last frost of September 30, which was very general, was forecasted in time to reach us, but unfortunately it reached us on Sunday morning. I succeeded in getting word to some of the stations, but most of the telegraphic stations were closed, and of course much damage was done. I do not think the conditions warranted the forecast being sent out on Sunday morning.

Mr. H. W. RICHARDSON (Ohio). In our State I knew pretty well that most of the crops had been cut and housed, and so it did not do much damage. I tried to reach some of the stations in the southern part of the State, and also in the vicinity of some of the northern counties, but I did not succeed very well.

Mr. HACKETT (Missouri). I wish to say a word with regard to the distribution of forecasts by the logotype system. I think that better service would result if the forecast messages sent to distributing displaymen were so worded, in all cases, that they could be exactly duplicated with the logotypes furnished them. Very few of the displaymen have time to write in words on the cards with pen or pencil, and when forecast telegrams contain words not included in the logotype vocabulary some try to change the wording of the forecast, while others omit a portion. As a rule, probably less than a dozen people see the original telegram, while the forecast as printed on the cards is read by thousands. The forecast official, or the official in charge of the station from which the forecast is telegraphed to the displayman, is better able to determine the words of the logotype vocabulary which will best convey the information contained in the forecast, and I think that in all cases the message sent to the displayman should be so worded that he will be able to duplicate it exactly.

Mr. LINNEY (Illinois). I have found very great difficulty in instructing the displaymen what flags to put up—whether for the day before or the day following. It seems to me that some better rule than we have at present should be adopted. The information that it is desired to give the people will be given to a great many more people by having

the flags for to-morrow displayed instead of for to-day, but we have the trouble of not receiving our forecasts until about 12 o'clock. Another difficulty is insufficiency of words in the forecast vocabulary. Oftentimes the meaning of the forecasts when telegraphed are not clear on this account.

Mr. SALISBURY (Washington). The forecasts are often so worded that displaymen find it difficult to determine what flag or combination the forecaster desires or intends to be hoisted. I have encountered the same difficulty myself, and it is likely that displaymen with limited experience are more frequently unable to decide correctly or with certainty. I advise the addition of two words to the message containing the forecast which would designate exactly the flags desired hoisted. It might be done by one cipher word if a code were furnished the displayman. The additional cost would only be trifling; in most cases it would not add at all to the present cost.

Mr. BRONSON (North Dakota). Referring to the size of the card, it may be well to encourage any change tending to reduce its size. The cards are so large that they become torn and ragged in being tied together with other mail, and when they reach us present a very untidy appearance. I think they should be cut to the size of ordinary mail.

Mr. BATE (Tennessee). I do not think the cards are too large, and if they are torn it is through the carelessness of the postal officials. But I do think there should be some improvement in the quality of the paper used. They use paper now that is very easily torn and mutilated. I think the present style of card is very good for the purpose for which it is used, and is distinguished from the ordinary postal card.

Mr. MITCHELL (Florida). Regarding the card in current use, my attention was called to its abnormal size, when compared with the ordinary postal and letters, by the postal clerks, who explained that cards were cut by the tiestrings owing to the difference in size of the mail matter. The present cards, however, give good service.

Mr. CHAFFEE (Alabama). I have a suggestion to make relative to the question, "Can any improvement be made in the present system of forecast distribution?" I would suggest that through the cooperation of the Post-Office Department our weather forecasts might be printed on mail matter as a part of the postmark. My idea is, that postmasters be furnished some simple outfit with which they could stamp the weather forecasts as part of the receiving postmark on letters, etc., delivered through their offices. Right above the present postmark should appear the words, "Weather to-morrow," then the weather and temperature forecast expressed in two words, as "Fair, colder," "Rain, warmer," "Clear, cold wave," etc., these words to be made as logotypes which could be interchanged with little trouble.

This would entail no extra work on the postmasters, and to my mind, would secure an unprecedented distribution of weather forecasts and warnings. If the present weather signals of two flags convey informa-

tion of any value, and they certainly do, then two words printed as suggested will convey even more. When we stop to consider the many million pieces of mail handled by the Post-Office Department—and while we could not expect to print our forecasts on all of them, if they can appear on even a part we will be doing much to familiarize the public with the Weather Bureau and to extend its benefits.

Mr. MITCHELL (Florida). In keeping with the ingenuity characteristic of the gentleman from Alabama, I think his suggestion a good one, and its adoption will be a significant medium in disseminating the daily forecasts.

Mr. Chaffee's suggestion was very favorably received, and provoked considerable discussion, Messrs. Huston, Hersey, Salisbury, Clark, McGann, Mitchell, Bate, Berry, Glenn, and Widmeyer participating therein.

On motion of Mr. Hersey, a committee, consisting of Messrs. Glenn, Townsend, and Chaffee, the latter as chairman, was appointed by the president to thoroughly investigate the practicability and benefits of Mr. Chaffee's suggestion, and to report to the president. The report of the committee will be found at the close of this pamphlet.

PROCEEDINGS AT THURSDAY AFTERNOON SESSION.

A number of the delegates desiring to leave on trains departing during the afternoon, it was decided not to undertake the discussion of the last two subjects, but to close the convention after the election of officers.

Mr. T. B. Jennings, in charge of the Kansas weather service, offered the following resolution:

Resolved, That in view of the fact that the Hon. J. Sterling Morton, Secretary of Agriculture, has not only faithfully stood by civil-service regulations, but has observed the true spirit of the law in filling such places in the national Weather Bureau as by reason of rank and salary were outside the pale of that law, and has even selected the head of the Service from the ranks of its practical workers, that the American Association of State Weather Services expresses its gratification, and recognizes the benefits which must accrue to the public service by applying such economical and business principles to the administration of a great weather service.

The PRESIDENT. Before submitting this resolution to a vote, I desire to express my hearty concurrence in the sentiments embodied therein. I wish to congratulate this association, the Weather Bureau, and the country at large upon the selection of the Chief of Bureau "from the ranks of its practical workers." We, as members of the American Association of State Weather Services, can appreciate the advantages that our organization will receive by placing one of our number at the head of the Weather Bureau, as our very existence depends upon hearty cooperation with the national Bureau. Our worthy Chief, having a thorough knowledge of the value of the State weather service work, can not fail to lend that aid and support so necessary to secure future success and usefulness. The employees of the Weather Bureau are to be congratulated,

because this selection assures them that there is a future for every employee, and that attention to duty and efficiency are certain to lead to advancement. In my judgment, no better selection could have been made for this important position, and it will prove an object lesson to the workers in the Weather Bureau which can not but result in extending the usefulness of the service. Professor Moore owes his position to-day especially to his proficiency in forecast work, and this, coupled with the fact that he possesses that judgment, energy, and executive ability which enable him to widely disseminate forecasts and storm warnings of special importance when and where they would prove of greatest value. It was his excellent forecast work, combined with what I may call his efficient outside work, which attracted the attention of the public and the authorities and commended him for the position which he holds. The country at large is to be congratulated upon the selection of such a Chief, for the reason that the past record of Professor Moore is an indication that the importance of the practical as well as the technically scientific work will be especially emphasized during his administration, and I am confident that no opportunity will be lost to improve the forecast work of the Bureau and secure wider distribution of its information for the benefit of the public. I feel sure that this resolution will have the unanimous support of the convention. I hope to have opportunity to render Professor Moore loyal support in his efforts to increase the efficiency of the Weather Bureau.

The resolution offered by Mr. Jennings was unanimously adopted.

Mr. Bate (Tennessee) spoke in behalf of holding the meeting of 1896 in his State at Nashville, and in connection therewith presented the following communications:

STATE OF TENNESSEE, EXECUTIVE CHAMBER,
Nashville, October 14, 1895.

American Association of State Weather Services, Indianapolis, Ind.

GENTLEMEN: Permit me, on behalf of the State of Tennessee, to invite you to hold your next meeting in the city of Nashville. The State of Tennessee will celebrate the one hundredth anniversary of its admission into the Union by holding a grand exposition in the city of Nashville during the autumn of 1896. Our people are making elaborate preparations to receive and entertain all visiting associations, and it is the desire of the people of the State, expressed through me, that the members of your association give us the pleasure of your presence at some time during the continuance of the exposition.

Yours, very truly,

P. TURNEY, *Governor.*

OFFICE OF THE MAYOR,
Nashville, Tenn., October 1, 1895.

American Association of State Weather Services, Indianapolis, Ind.

GENTLEMEN: We take great pleasure in indorsing the invitation extended by the chamber of commerce to your honorable body to hold your next annual meeting in this city—our centennial year. We will see that you receive a most cordial, hearty greeting, and that your stay shall not only be pleasant but profitable to each of you individually.

Very respectfully,

GEORGE B. GUILD, *Mayor.*

Communications were also received through Mr. Bate from the president of the city council of Nashville, the chairman of the board of public works, the chairman of the chamber of commerce, and the director-general of the Tennessee Centennial Exposition. The success of the Indianapolis convention being largely attributable to the central location of Indianapolis, and Nashville possessing practically the same advantages, it was decided without opposition to hold the convention of 1896 in the latter city.

Upon motion, the following resolution was adopted:

Resolved, That a vote of thanks be tendered the Indianapolis Board of Trade for their warm welcome and magnificent entertainment of the members of the American Association of State Weather Services during its convention in their city October 16 to 17, 1895, which the members of the association will long cherish as the most marked attention yet paid them by any commercial body or other organization since the establishment of the association.

Resolved, That the secretary of this association be instructed to forward to the president of the Board of Trade of Indianapolis a copy of these resolutions.

Letters were received from many voluntary observers and others cooperating with State weather services, expressing regret that they were unable to attend the convention.

A number of interesting papers were also presented, and it is regretted that it will be impracticable to publish several possessing much merit. Those given at the end of this report will doubtless prove of much interest to all interested in State weather service work.

The following officers were elected to serve for the ensuing year: President, Maj. H. H. O. Dunwoody; first vice-president, Mr. H. C. Bate; second vice-president, Mr. F. H. Brandenburg; secretary, Mr. James Berry; executive committee, Messrs. E. A. Beals, I. M. Cline, and B. H. Bronson.

The election of officers concluded the work of the convention, which was adjourned to meet in Nashville, Tenn., in the autumn of 1896, the date to be determined by the president and executive committee.

BIOGRAPHICAL SKETCH OF INCREASE ALLEN LAPHAM.

By his daughter, Miss JULIA A. LAPHAM.

Increase Allen Lapham, to whom the country is largely indebted for the establishment of the United States Weather Bureau, was from his earliest boyhood a lover and student of nature. He was one of a large family of children, and obliged from the early age of thirteen to contribute his share toward the support of the family. While working with his father (who was assistant engineer on the Schuylkill and Erie canals) at Lockport, Dr. Lapham collected his first fossils, which were the foundation of his fine collection that became the property of the State of Wisconsin in 1876, after his death, and was burned in Science Hall of the State University in 1884.

In 1827 the family moved to Shippingsport, Ky., and the son became a rodman on the Louisville and Portland Canal, with the understanding that he should attend the

Jefferson Seminary, then under the charge of Mann Butler, the historian, when his services were not required on the canal. Very soon the canal duties occupied all of his time, and all thoughts of school were given up.

It was one of the great disappointments of his life that he could not secure a college education. An occasional day at school was all the time that could be spared from the duty of earning his own living and assisting in maintaining the home. His only education was acquired by reading, observation, and a life-long correspondence with men like Silliman, Sullivant, Isaac Lea, Darlington, and Joseph Henry, who had become interested in him by the exchange of specimens from his Western home.

Dr. Lapham was a careful reader of all scientific books obtainable, and in 1827 became a subscriber and writer for Silliman's Journal.

On receiving his first article, written when only 16 years of age, Prof. Benjamin Silliman wrote: "It speaks well for your habit of observation, unusual in one so young. Time will (perhaps sooner than you realize) remove the difficulty of youth, and I trust you will improve year by year in everything wise and good and become a blessing to your fellow-men." Almost a prophecy, as he lived for others more than himself; was ever ready with kind sympathy for all.

A very voluminous correspondence was carried on between Dr. Lapham and an older brother, also an engineer, and interested in the sciences. Every walk to Louisville, or along the bank of the canal on his daily rounds, furnished matter for these letters; some new flower discovered, an unusual number or variety of birds, a rotten log turned over revealing a new shell, some Indian relics thrown out by the workmen making the canal excavation, or possibly a sketch of some improvement in locks or bridges, the plan for a railroad around the Falls, or an account of an excursion with Victor Audubon to collect specimens for his distinguished father.

The curiosity of these brothers was excited by the boulders scattered over the country. Every locality in which they lived was explored and notes made to be discussed in following letters. Not being satisfied with the theory that an immense lake at one time covered the country, as there were no barriers to raise the water to the height necessary to cover the highest boulders—nor yet with the idea that boulders were created where found, or were thrown out by volcanoes or earthquakes, they formed theories of their own.

That meteorology and kindred subjects were of interest to him in these early years is shown by the frequent mention of the state of the weather in his diaries and letters, and comparisons with other years and places.

The temperature of the Ohio River, especially during the flood of 1828, was taken at the surface and below and compared with the temperature of the air.

The following table of Dr. Lapham's observations at Shippingsport was published in *The Focus*, a Louisville weekly paper, in 1827. Later, he kept and published each month a record of the thermometer; no copy of these records is in existence unless in some file of *The Focus* or the *Louisville Public Advertiser* for 1828-29:

	Fair days.	Variable days.	Cloudy days.
September 15-30, 1827	8	8	4
October, 1827	9	7	15
November, 1827	6	6	18
December, 1827	5	3	23

When Dr. Lapham arrived in Milwaukee, in 1836, he began a study covering the whole of his adopted State. In its climate he was specially interested as possessing some peculiar features arising from the topographical and geographical position of the State, occupying as it does a portion of the two great valleys of the continent—the Great Lakes and the Mississippi. This interest led to the publication of the map of Wisconsin with the isothermal lines.

As a member of the Milwaukee Lyceum, in early days, he was appointed meteorological observer, to note and report at the meetings each week the wind, the rain, and the temperature; and as a voluntary observer he continued this work until the organization of the meteorological work of the Signal Service, frequently in threatening weather taking hourly and half-hourly observations.

Dr. Lapham's interest in the effect of storms on Lake Michigan was soon aroused, and a list of disasters was prepared by him and Mr. F. Randall in January, 1842, for a report to the trustees of the town of Milwaukee on the commerce and navigation of Lake Michigan. The list extended from January, 1834, to January, 1842, and considering the small number of vessels on the lakes in those early times, was appalling—118 lives were lost, \$1,052,450 worth of property destroyed, and 89 vessels more or less injured.

In 1848, as one of the faithful band of observers for the Smithsonian, working for the love of science and the good of his fellow-men, he suggested to Prof. Joseph Henry that much more satisfactory results might be obtained in securing elevations by simultaneous observations on standard instruments at the same level whenever possible, and also suggested that instruments be furnished the Milwaukee High School.

By means of observations taken every three hours during the month of August, 1849, Dr. Lapham discovered that there was a lunar tide on Lake Michigan. He published this fact in the Milwaukee Sentinel and Gazette of September 3, 1849.¹ Ten years later this discovery was verified by the self-registering tide gauge placed by Capt. George G. Meade, superintendent of United States lake survey, on the pier near the entrance to the Milwaukee harbor.

In 1850 Dr. Lapham prepared three memorials to be presented to the legislature of Wisconsin, one for the board of trade, Milwaukee, another for the State Medical Society, and a third for the State Agricultural Society, urging that an appropriation of at least \$1,000 be made to purchase instruments and establish a regular system of meteorological observations throughout the State of Wisconsin to ascertain the laws which regulate and govern storms, and by this means prevent to some extent the great annual loss of life and property on the Great Lakes.

This memorial also claimed that the knowledge of such laws would be of use and interest to all classes of men, especially to the farmer. That Dr. Lapham considered such knowledge would be of use to the physician is proved by the fact that he prepared a memorial for the medical society.

This being before the days of the common use of the telegraph, the greatest hope was to secure a series of simultaneous observations for a number of years, and from this decide on the probabilities for the coming season.

The memorial reads: "To say that we may soon be able to predict the general character of the coming season with certainty may seem presumptuous, and yet it would be far less wonderful than many similar discoveries recently made. If the life of a single individual engaged in commerce on the lakes, or if one steamboat or sail vessel can be saved by this means, the State might be considered amply remunerated for the expense."

¹ The discovery of the lunar tide here ascribed to Dr. Lapham was undoubtedly announced rather prematurely, but Dr. Lapham's early publication may have stimulated the Chief of Engineers to order an investigation of this subject by the officers in charge of the survey of the Great Lakes. The real lunar tide in Lake Michigan was found to be so small that it is obscured by the solar tide and by the influence of the winds, the rain, and the barometric changes. It required several years of continuous self-registration and a careful mathematical analysis to establish the existence and extent of the lunar tide that had been predicted by the theory of gravitation.—(Signed) C. ABBE.

This effort was unsuccessful, but from that time Dr. Lapham used his influence in every possible direction to make some attempt to prevent the fearful results of storms on the lakes, urging the legislature, boards of trade of different cities, transportation companies, and private individuals to make the experiment, which he was sure, from his knowledge of storms and of what had been done in predictions, would be a success, but without avail, frequently meeting with ridicule or pity that a man should be so "carried away with a hobby." Strong in his convictions, he worked on, further study confirming his faith, until after twenty years' waiting the Government was induced to take up the matter.¹

Although not the originator of the idea that storms could be predicted, yet, as Prof. Joseph Henry, of the Smithsonian, truly says, in a letter dated February 3, 1876, "the action of Congress in securing the storm signal service was due to the immediate exertions of Dr. Increase Allen Lapham, through the Member of Congress from his district, Gen. H. E. Paine, in setting forth the advantages of the system in the commercial interests of the Great Lakes."

When the meteorological service was organized in connection with the Signal Corps of the Army, of which Gen. Albert J. Myer was the Chief, Dr. Lapham accepted the responsible position of assistant to the Chief. The conclusions he drew from the daily reports were telegraphed to Washington, and from there sent to the lake ports, as predictions.

Dr. Lapham ceased forecast work in December, 1870, and resigned this position when he was appointed State geologist of Wisconsin in 1873, but did not lose his interest in the work, frequently preparing lists of disasters, tables of the mean temperature of various places, etc., which were of great interest to the community.

Dr. Lapham was a local authority on all scientific subjects, and was often appealed to "from city, State, and country" for information which he alone could furnish. Those well acquainted with him had no less cause to admire his modest, unassuming manner than his profound learning. "Socially he was genial, affable, and hospitable," writes a friend; "scientifically he was laborious, patient, conscientious, and unpretentious. He toiled for science from a love of science, but with a thorough and intelligent comprehension of the great possibilities that lie in the field of research. There was no bidding for popular applause in anything he did; his modesty was extreme, and his unselfishness was manifest in the care he took to give due credit to all."

IMPORTANCE OF STATIC ELECTRICITY IN WEATHER BUREAU WORK.

By E. A. BEALS, *Weather Bureau, in charge of Minnesota Weather Service.*

The Weather Bureau is engaged in two distinctive lines of work, which in one sense are widely divergent, while in another they are closely allied and interdependent. The first and foremost field, and the one upon which our Bureau chiefly depends for its popularity, is that of forecasting the weather, and this science is now but slightly further advanced than was astronomy in the hands of the Assyrians and Egyptians some four or five thousand years ago. In those early days successes in forecasting astronomical events did not greatly exceed the failures, although they were sufficiently accurate to maintain the masses in the belief that a vast amount of knowledge had been acquired by their learned men, who, in consequence, were highly esteemed.

To obtain the largest sphere of usefulness, we must bend all our energies to the attainment of the utmost efficiency in weather forecasting. As fast as improvements

¹In 1869 he cooperated heartily with the Observatory at Cincinnati by sending daily reports for the weather bulletin of the Chamber of Commerce, which, with its daily probabilities, was issued under the direction of Prof. Cleveland Abbe.—WILLIS L. MOORE.

in this line are made just so fast will methods open up for disseminating such information most thoroughly and widely to the people, whether living in cities or in thinly settled communities.

That other branch of work undertaken by the Weather Bureau, which in popularity almost equals that of forecasts, is the weekly weather crop bulletins, wherein we treat of crop growth as affected by the weather. We wish by furnishing information on these two lines to keep the public advised of how best to employ their forces so that weather conditions, instead of operating to cause losses, may, as far as possible, be profitably taken advantage of. Or, in those cases where losses are inevitable, we have in view to so inform, that the least possible harm can ensue. To be able to comprehensively treat these matters, upon which our energies are most strongly centered, it is very essential that every atmospheric component known to bear on the question be closely studied.

We have done this so far as temperature, pressure, rainfall, humidity, and sunshine are concerned, but there yet remains an element having in some subtle way a most powerful influence on crop growth, which in addition can also be used most efficiently as an aid in forecasting rain and perhaps wind. This element is the electrification of the atmosphere, and so far as I know has never been used by the Government weather forecasters or discussed in crop bulletins as to its bearing on plant growth.

It is the object of this paper to give a few facts showing the important part atmospheric electrification plays in connection with crop growth, and how valuable it might be in assisting the forecaster to improve rain predictions, especially in the Northwest, where so many storms pass from the northern Rocky Mountain district to the Great Lakes before producing any rainfall of consequence.

In treating of the subject of crop growth we are confined exclusively to the part weather exerts upon plants, and this factor is by far the most important one of all. Temperature, rainfall, and sunshine are usually given as the dominating causes of whatever results it may be necessary to chronicle each week. These elements undoubtedly enter most prominently into the case, but that of electricity is one that can not altogether be neglected, for recent researches, made almost exclusively by foreign scientists, show that by withdrawing this atmospheric component vegetation remained very backward as compared with that not interfered with.

On the other hand, experiments made in France have conclusively shown that by increasing the atmospheric electricity received by plants a most marked increase in both growth and yield will follow. Other experiments made in Europe tend to show static electricity to be a powerful factor in stimulating growth in wheat, barley, oats, hemp, potatoes, beans, leeks, tomatoes, beets, parsnips, raspberries, and strawberries, but did not act favorably on peas, carrots, turnips, cabbage, or tobacco. In some of these experiments the production of root crops were quadrupled, while other plants were doubled or tripled. No deterioration in quality resulted from increased growth caused by electricity, which is often the case where large yields are obtained by means of irrigation.

The invigoration of plant life by electricity also tends to show, especially in the case of vineyards and orchards, that they are better able to withstand insect ravages, and perhaps it will not be long before spraying will give away to an inexpensive treatment of electricity that will solve the problem of insect pests now occupying so prominent a part in agricultural economics. It is patent to the dullest observer how revivifying a smart shower of rain often is to our city lawns. These rains, which may give only a very small quantity of moisture, cause the grass to fairly spring from the ground. The lawns were previously abundantly watered by hose, but no great growth ensued until after one of these showers, when all nature seemed to undergo an almost immediate transformation into renewed vigor and healthfulness. Such rains must carry down with them a great deal of electricity from the upper atmosphere to so stimulate growth, for the water alone can not do it, as demonstrated

by the fact that sometimes other and greater rains, or abundant sprinkling with the hose do not produce such effects. It has even been clearly proven that an electrification of seeds often accelerates germination and growth, through the life stage of the plant thus treated.

Our experiment stations are so occupied in the matter of educating the farmers into better methods of soil culture; how to overcome the ravages of insect pests; advising how to improve live stock through breeding and feeding; how to prevent disease in vegetation; providing better seeds, and in many other minor ways, that but little attention is given to the weather factor involved and still less to the part played by its component of electricity. Their neglect leaves the field open to the Weather Bureau, and it should promptly grapple with it, for it is a most promising field and properly within its province under the liberal management now controlling its destiny.

Intensified farming is the order of the day. The world's population is increasing with alarming rapidity, while our land area remains fixed. The problem confronting future generations and is not so far ahead as many people think, is how to raise sufficient to feed the growing multitudes. Therefore smaller farms and increased yields are the great desiderata. To meet this requirement what field is more promising than that of utilizing the electrification of the atmosphere, and where will you find a better medium to undertake its accomplishment than through the efforts of the Weather Bureau, with its corps of trained observers.

In 1871, Prof. I. A. Lapham, one of the prime movers in the organization of the national Weather Service, said in a report to the Chief of the Signal Corps, regarding the value of instrumental observations of atmospheric electricity, that if they were practical, "an additional certainty would be given to the daily conjectures of the 'probabilities' of the occurrence of storms." Observations of this nature were then not practicable, owing to the delicate nature of the instrument employed and on account of the personnel of the corps not being sufficiently well trained to look after them. Twenty-four years ago the importance of applying changes in electrical potential as an aid in forecasting were fully recognized, but not then considered practicable for reasons that now no longer exist.

The value of our work has become a fixed necessity. The public demand that we give them the very best service that money will buy, and they are willing to pay for it; therefore the matter of cost of delicate instruments which even to a very small degree operate to improve forecasts need not prevent their use, and it can no longer be said that the personnel of the Service is not sufficiently well trained to care for them.

We know that almost always rain is preceded from 2 to 24 hours or more by a change in electrical potential, and that during rainy weather a change from negative to positive electrification is an equally certain sign that it will soon clear up. With this knowledge, how is it possible to longer neglect the application of this factor in our daily work of forecasting weather changes, and at the same time publicly maintain that our forecasts are the best that it is possible to issue. I believe when we have as much statistical information regarding atmospheric or static electricity as we have regarding the least studied of other elements now receiving attention in our daily reports, that we will be in possession of knowledge the application of which will not only wonderfully improve our forecasts but will materially increase the value of our crop reports.

We should be able to state in the latter that the corn during the week has received deficient sunshine, the absence of which, however, was not harmful, owing to a preponderance of electricity of the proper sign, positive or negative; and the lack of moisture experienced has as yet done no injury, owing to the temperature being slightly less than the normal. These four elements are the dominating influences connected with plant growth, and should always be mentioned in our reports if we wish to truly chronicle the effect of weather on vegetation.

There is much more that could be said in favor of our Bureau taking up this question of atmospheric electrification with a view to its practical application in weather forecasts and crop reports. Its bearing in the new field of sanitary climatology is of equal importance, and in that other great realm of psychology, which as yet is only just opened to our view, it plays a most important part. In answer, therefore, to the sixth topic of discussion at the fourth annual convention of the American Association of State Weather Services, I would suggest that this question of atmospheric electricity be the one whereby special investigation can be undertaken by both the State and national weather services with best results.

MINNEAPOLIS, MINN., *October 13, 1895.*

HOW BEST TO SECURE AND RETAIN THE SERVICES OF VOLUNTARY OBSERVERS.

By Mrs. L. H. GREENEWALD, *Voluntary Observer, York, Pa.*

The bone and sinew of each respective State service and its life's vitality are found at the central office. But the germs of its extended growth abide with the individual local observer, and the development of his respective station will impress that community favorably or otherwise with the value of the State service, and its best work as a whole may be overlooked and unappreciated on account of unfavorable presentment by the local observer.

The retention of the voluntary observer appears to be the gist of the question, though the reply embodies a reversal of the subject under discussion.

First, his interest in the work must be secured. Promptness and accuracy are indispensable in the daily work of observations. Without these, inaccuracies will creep in that will eventually render the record of that station valueless, and especially so locally. To meet these demands requires frequent denials on the part of the local observer of which the central office or the public at large can have no adequate appreciation. Especially is this the case where the observer is so situated that a substitute can not be depended upon to take observations during the absence of the regular observer when fulfilling engagements of profit or pleasure.

The summing up of a few figures in the State bulletins at the close of the month seems a poor return for the expenditure of time, and often labor, in producing the result. A greater showing of the work of the respective stations in the State reports and the results secured in the departures locally in temperature and rainfall of the working stations would be a great stimulus to advance and further that work locally and draw the attention of the local press, to whom the reports are contributed, to the advancement of the service and its accomplishment of a work that really in a great sense is of a greater local benefit than its dissemination as a sum total over wider districts. Naturally, the reference to local conditions would interest each respective newspaper and draw especial attention and comment to the local station, whose observer, either through want of time, influence, or excessive modesty, failed to make a personal presentment of local conditions. Newspaper reporters following in this marked-out track would naturally interrogate the local observer, and the State service would thus assume proportions previously unthought of.

The State service is generally looked upon as an auxiliary to the United States Bureau. But is not the blending of the reports in the State summaries a discouragement to the voluntary observer?

Admitting that the United States Department is more scientific, of longer duration, and reasonably, as a whole, more accurate in general summaries, their blending places the work of the State service in the shade and depreciates the work of the voluntary observer in the minds of the public as a factor that has not sufficient stamen to exist without the support of the United States Department. Let the reports be included in the same bulletin, but under other headings and separate;

and though a greater work in arrangement would devolve upon the director at the central office, the increased interest on the part of the voluntary observer would eventually make adequate amends.

If there must be a rivalry for the stimulus of greater scientific efforts, let it be between the stations of each respective State service and a special feature made of the work of the best managed stations. This would arouse ambition among the voluntary observers to secure increased mention by better and wider work. The State service is, presumably, not scientific. Rather is it a patient record of daily weather events, that when properly arranged and tabulated becomes a most valuable history of meteorological conditions in each locality thus represented, and as an official record will become a valuable historical adjunct for the section represented, and thus secure a local status for the voluntary observers if understandingly presented to the public through the local press. This is the "keystone of the whole arch"—local work. Each year increases its value and secures an influence that must become legislative and eventually set aside the extended opposition to State weather service appropriations.

The return for the voluntary observers' work other than the local status to which their individual work entitles them, are the publications of the United States Department. No praise is too great for their scientific value, but they fail to interest the voluntary observer because they are too scientific. The voluntary observer, generally speaking, must be educated up to the first and early principles of the work he is expected to perform, and the future of the State services depend upon these means. The dissemination of the bulletins of the various State services cannot be too highly spoken of, and acknowledgment is made with thanks to the Oregon State weather service, B. S. Pague, director, and also to the Michigan weather service, C. F. Schneider, director. Especial mention is made of the latter in the August bulletin (vol. 10, No. 9), which contains many ideas of great benefit to any one interested in climatology. Independent of the August review and compilation of September weather, the dissertation on "Protection from frost" is of particular interest, and was issued at a most opportune time. Let this line of work become an object to interest the voluntary observer over all districts wherever the bulletins are forwarded.

Each director, judging as to the needs of his respective district, should bring forward those needs in simple language. The distribution of the bulletins will meet individual observers glad to be informed upon points of which they feel their ignorance. Let simple instructions be given from time to time involving in simple terms the whole work of the service, the manner of securing the normal of barometric readings and their application, also of temperature and rainfall record and the keeping of the departure from the normal of the respective stations, using the most simple terms, and figures fully carried out for the dropping or continuing of fractions in their balances, and reducing to whole numbers, etc. Simple instructions in cloud readings, their growth, overflow, etc., would be of inestimable value in securing interest and keeping it. The very simplicity of these matters have probably caused them to be overlooked as a need. But there are, doubtless, intelligent observers who are ready for and capable of efficient work, who have never known or who have forgotten simple methods for securing a result, and whose pride would forbid its acknowledgment to the director of the central station, and causes the return of imperfect and unfinished work not so much from lack of inclination as of instruction.

Filling this need of what is required to retain the voluntary observers answers the question of how to obtain them. The wider dissemination of the work and the simplicity of its explanation will enlist the interest of others and cause a constantly growing desire to add to local status, if no other motive presents, by joining the ranks of the voluntary observers. But to stations in full working order, the greatest need to those which are established locally and issue weather bulletins and report to the local press, is a large blank card, franked and directed to the respective newspapers, who are glad to issue these climatological conditions. The expense of a well-man-

aged station, when kept before the public, is an item the aggregate of which is surprising to the uninformed.

STATE WEATHER SERVICES: THEIR IMPORTANCE AND EQUIPMENT.

By A. J. MITCHELL, Observer in Charge, Florida Weather Service.

It is essential that methods should be adopted whereby the human family may enjoy all possible immunity from unfriendly weather changes and receive the benefit of those climatic elements which insure happiness and the prolongation of human life.

To those familiar with the facts it is superfluous to say that State weather services can be made indispensable auxiliaries in carrying out the plans of the national Service. Properly organized, with a corps of intelligent, zealous, and interested observers, there is no superior or more effective medium of reaching the public than through the instrumentality of these services. Primarily, it behooves every director to exercise more than ordinary care in the selection of observers. An observer may be ever so faithful, yet if his primary education is deficient his faithfulness is not always sufficient to offset the lack of ability.

Promptness is a cardinal virtue in meteorological work, and without it, is a case of "love's labors lost." It is too frequently the case that necessity or expediency dictates an appointment wholly unfit for the duties of an observer, resulting in unsatisfactory and worthless work. It is better to have no record than to accumulate data based upon observations incorrectly taken and the use of instruments little superior to the 10-cent thermometer of commerce. In the course of time State normals will be deduced from these records, and a false premise always leads to erroneous conclusions. Speaking more directly on the importance of State weather services, it is patent that only through this medium can local climatic features be established and the benefits to certain products arising from the proximity of sundry bodies of water and other surroundings fully appreciated.

During the past winter we had striking instances of this citation, for you may be aware that occasionally an icy blast reaches the peninsular region of Florida. However, there were sections where the ill effects of frosts were not felt, and some of our friends in the "land of flowers" could not refrain from the propriety of giving the cognomen "Frost proof" to a favored section, and we are here reminded that a frost-proof region in the times of blizzards is no less appreciated than a bombproof locality when the clash of arms is imminent. State weather service data give authentic information regarding seasonal, excessive, and annual precipitation, so important to engineers in regulating the depths of canals and perfecting systems of drainage, both highly essential in the agricultural and hygienic world. State weather service reports are frequently consulted by engineers engaged in the construction of expensive structures regarding the excessive hourly falls of precipitation. This information is of no little importance in determining the size of conduits for carrying off excessive volumes of water. A recent application for the above information, where the value of the building was quite \$500,000, attracted attention.

The wise and skillful physician no longer relies on the *materia medica* as the last resort of the healing art; on the contrary, he consults the meteorological data of the various States, compiled by the national Bureau. From this fruitful source can be largely gleaned the necessary temperature data, particularly the daily, monthly, and annual means, extremes, ranges, prevailing winds, and precipitation, not to mention the number of clear and cloudy days. This information, tabulated and in an acceptable form, thanks to State weather services, can be given for almost every village throughout the country. We know that the climate of different sections of almost every State differs, being largely influenced by surrounding conditions; and by climate we mean the temperature, cloudiness, precipitation, winds, and other meteorological features. For instance, Florida has both a marine and continental climate. Continental is used advisedly and in a comparative sense. The lower peninsular

region, bathed by ocean and gulf, never loses its verdant freshness, while the northern section of the State early succumbs to biting frosts. In computing the mean temperature of the State and studying the adaptability of sections therein to the growth and development of certain products, it is advisable to divide the State into subdivisions, and consider the proximity of gulf and ocean, lakes and rivers, that we may know what part they play in our immunity from frosts and chilling winds. This information can be gotten with exactness from State weather service records only. In keeping with a spirit of progress, voluntary observers should be utilized in perfecting a more satisfactory record of thunder storms, and telegraphing to centers the occurrence of local disturbances, especially when the latter play an important part in the weekly data for crop reports.

As previously asserted, the data compiled by voluntary observers enable interested parties to decide the adaptability of sections and counties to the growth of agricultural and horticultural plants. While this information can be given, approximately, by referring to stations of the national service, it is more minutely and satisfactorily compiled from the records of voluntary observers. From the same source landed corporations, in setting forth the unrivaled attractions of their holdings, are not slow to grasp the situation, and as their "leader" point with unerring regularity and confidence to the climate of their State. A section of Florida was once questionably advertised as the only perfect thing under the sun. This, however, was before the freeze. The State immigration agent with grip well stored with literature, or, more properly, advertising matter of the recourse of the State, faileth not in being replete with weather statistics, not only of the State but of each county therein. The possession of such voluminous matter and local official data has been made possible by the generous cooperation of voluntary observers. The village physician, though isolated from scientific centers, has recourse to the records of voluntary observers, from which he is enabled to study the effects of local climate on prevailing diseases. It is well known that the health of a town or city, especially over inland sections, can be fairly measured or is materially affected by certain winds. This fact is so strongly recognized in Florida that the inhabitants along the eastern section, or more properly the Indian River country, have honored the southeast breeze with the professional title "doctor," and their doctor is an antidote for the malaria of the interior. With the local meteorological record the physician can chart the various diseases, the latter fluctuating with the excess or decrease of moisture and the rise and fall of thermal conditions.

The collateral information promulgated by State weather service publications surpasses in importance all publications of the Bureau, and is no mean competitor, in point of general value, to the daily forecast. To the army of unselfish, interested, and faithful crop correspondents too much praise can not be given, and we are not far wrong when they are styled the "right arm of State weather work." To them is due the successful effort of laying before each interested inhabitant, hamlet, town, city, county, and State the exact condition of every crop in every county in every State once each week. This information is largely disseminated by the daily press, and, posted as it is in many public places, presents to the public invaluable crop statistics. To whom, in particular, is such information valuable? Valuable to the merchant, who advances supplies and whose reimbursement is dependent upon a successful crop; valuable to the farmer, apprising him of the progress and condition of crops similar to his in adjoining counties and States; valuable to the nation, as through this medium all classes receive information; valuable to labor, by the sweat of whose brow all products come forth, and whose countenance is wreathed with smiles at Heaven's benignant gift, a plenteous harvest; valuable to transportation companies, by which they judge prospective traffic; and, lastly, valuable to the speculator, by whose unrighteous deals a "long" crop is made "short" and a "short" one "long."

If there are vulnerable points in State weather service work, it is to be found in the lack of uniformity of instruments used and the exposure of the same, and until

these are corrected the observations will not bear that scrutiny desirable and necessary in official records. The remedy lies in the equipment of all stations with standard registering instruments; and why? Because it is not always convenient for voluntary observers using the dry thermometer to take observations on time, making it possible for serious errors to creep into the work. A passing thunder shower frequently calls the energetic, live, and progressive farmer to the field, else he may lose valuable hay, fodder, or other products easily damaged by moisture.

The next suggestion requiring attention is the exposure of instruments, and it may not be inappropriate to relate the following incident, confirmatory of the above assertion. A prominent and faithful observer of a near-by State, on being interrogated regarding the exposure of his instruments, made the following reply: "In the summer I expose the instruments from the south side of my house to get the greatest amount of heat; in the winter time they are exposed from the north side of the house to get the greatest amount of cold."

To perfect the system the "cotton region" instrument shelter should be adopted; and with an occasional visit from the director to inspect and come in personal contact with observers, making known the value of their reports and the appreciation of them by the Bureau, State weather services will have taken a long step in the direction of usefulness, and merit enhanced appreciation of public confidence.

HISTORY OF THE SOUTHERN CALIFORNIA WEATHER CROP BULLETIN.

By GEORGE E. FRANKLIN, *Observer, Weather Bureau.*

During the crop season of 1890 Mr. James A. Barwick, then in charge of the station at Sacramento, Cal., inaugurated the publication of a weekly weather crop bulletin, based upon reports received from the entire State of California. After a season's trial the system of publishing a bulletin for the State in its entirety was found inconvenient and impracticable, owing to the immense territory embraced in the State, which prevented the reports from southern California reaching the director in sufficient time to be incorporated in the weekly telegrams to the office of the Chief of the Bureau for the national weather crop bulletin. Therefore it was decided to have the weekly reports from the correspondents in southern California mailed to the observer in charge of the Los Angeles station, where they were to be summarized, and a synopsis of the information in regard to the condition of the crops and weather telegraphed to the director of the State service, by which means the desired information would be available for publication in the State bulletin and for communication by telegraph to the authorities at Washington for use in the national bulletin, and where a bulletin for the southern portion of the State could be published. As early as practicable after receiving authority to commence this work and the necessary instructions in relation thereto, the writer of this paper placed the subject before the people through the press and by correspondence with representative citizens of the various agricultural and fruit-raising districts, and by their aid and hearty assistance obtained correspondents from the principal places, and on March 21, 1890, the initial number of the southern California weather crop bulletin was issued. It soon passed the experimental stage and became an established feature of the Bureau's work at this station.

In the beginning some little difficulty was experienced in carrying out the scope and intent of this work, owing to the fact that the people were not familiar with its design; but, as the project unfolded and the information contained in the bulletins was laid before the public by means of free distribution of the publication in conspicuous places, and through the aid of the press in publishing the reports in detail, and by "news notes" and comment, the people soon saw the benefits to be derived from authentic and unbiased reports of the crops and climatic condition of the country, and readily assisted in the endeavor to make the publication a success.

The southern California weather crop bulletin has been published continuously from its inception, and, owing to the peculiar climatic conditions of this favored land, the issue has been for each week in the year; the winter edition, or rather its calendar equivalent, receiving more attention from the public and being more highly appreciated than those of other periods. These months are in this section a season of active growth of all products of the soil and the time of harvesting of the citrus fruits.

With reference to the issuance of bulletins during the winter months as well as during other periods of the year, I desire to submit to your attention the following statement, which shows that fruits ripen all the year round; and this, in connection with the fact that the winter months, or the rainy season, is a period of active farm work—a period where east of the mountains nature is dormant and farm work impossible—fully justifies, I think, the time and labor expended on the publication; this is amply shown by its popularity and the steadily increasing demand for wider and fuller meteorological information.

Fruits ripen as follows: Oranges, all the year; lemons, all the year; limes, all the year; figs, July to Christmas; almonds, October; apples, July to November; pears, July to November; grapes, July to December; peaches, June to Christmas; apricots, June to September; plums and prunes, June to September; Japanese persimmons, November and December; guavas, nearly all the year; loquats, May and June; strawberries, nearly all the year; raspberries, June to January; blackberries, June to September; currants, May and June; watermelons, July to December; mulberries, July to December; nectarines, August; olives, December and January; pomegranates, September and December; quinces, October to December.

As an instance of the esteem in which the southern California weather crop bulletin is held, I desire to state that the Los Angeles Chamber of Commerce, probably one of the, if not the most public-spirited, and on account of the free exhibition of southern California's products in its halls the most unique institution in the United States, published at its expense, in cooperation with the Weather Bureau, the bulletin in a neat and attractively printed form during the winter for several seasons.

While the southern California weather crop bulletin has become an established and in many respects a successful publication, yet there are features which militate against its continued success; and among these is the difficulty of retaining reliable and competent correspondents, and the laborious and unsightly milligraph process of issuing the publication, especially during the warm months. The present system of furnishing copies of the bulletins and such other publications authorized by the Chief of the Bureau does not work well, as in many cases correspondents after sending in a few reports give up the task because of the, to them, inadequate compensation in return for services; and further, from the fact that the character of the information furnished is very much curtailed in the bulletins. The writer of this article is of the opinion, based upon experience, that if a plan can be devised of establishing an organized force of correspondents who could be displaymen, or otherwise agents of the Weather Bureau, at a small monetary compensation, a tangible and direct hold could be obtained whereby a sufficient number of correspondents could be secured, so that creditable publications could be issued. Perhaps this could be done by means similar to those employed during the cotton season, when reports are received of the temperature and precipitation at State centers. In regard to the milligraph process, while the work is as legible and neat as the process will permit, the bulletins should be printed, and the writer thinks in a uniform style throughout the service.

DISCUSSION.

The following remarks on several subjects in the official programme were submitted by Mr. C. F. von Herrmann, observer, Weather Bureau,

and assistant director North Carolina weather service, Raleigh, N. C. Mr. von Herrmann did not attend the convention:

1. HOW BEST TO SECURE AND RETAIN THE SERVICES OF VOLUNTARY OBSERVERS.

In North Carolina the larger number of our voluntary observers are professors at the various colleges in the State, or physicians, who are more interested in the work of the State weather service and better understand its requirements than any other class. The increased amount of time devoted to meteorology in the schools, and the interest evinced by the medical fraternity in sanitary climatology is evidence of this fact. New observers at selected places are obtained by personal correspondence with prominent persons of that class, and an explanation of the aims of the service rarely fails to enlist interest in our work. Printed circulars indiscriminately distributed asking for volunteers have never been of much use. No inducements are offered beyond the usual promise that observers shall receive the publications of the national and State services. In my State all voluntary observers, displaymen, and crop correspondents also receive copies of the bulletins of the North Carolina experiment station, with which the weather service is connected; and as such publications are often very interesting and valuable, it is suggested that in other States where there may be no cooperation with the State experiment station the bulletins of the latter could probably be obtained for voluntary observers on request.

I think there will be no difficulty in retaining the services of voluntary observers if they are made to see that their work is properly valued and appreciated by the directors. At this station the courtesy is never omitted of a prompt acknowledgment by letter of the receipt of each voluntary observer's monthly report, and I would suggest the advisability of the issue of a postal card form for that purpose by the Weather Bureau. The occasional visit of a regular inspector would often renew the flagging zeal of many voluntary observers, by affording an opportunity for conversation and an interchange of ideas on meteorological topics.

It is undisputed, however, that no more patriotic class of citizens exists than the voluntary observers throughout the United States. Many have kept up their labors faithfully for long periods, and without their assistance the work of the State weather services would be impossible. I move, therefore, that the convention pass a suitable resolution in recognition of the value of the work of voluntary observers, and expressing the appreciation of the directors of State weather services in their cooperation.

2. IMPROVEMENT AND DISTRIBUTION OF CROP BULLETINS.

Most of the crop bulletins now published are admirable. The chief improvement which might be suggested is the addition of a rainfall and temperature chart. Unless, however, such charts can be as neatly reproduced as those contained in that model publication of the kind, the national crop bulletin, I do not advocate their use. Some of the rainfall charts now published in State bulletins are neither elegant nor edifying. In my opinion, a selection of the remarks of crop correspondents should always be printed, and rather than be omitted the general summary should be curtailed. There is a possibility of making the crop summary too long and too minute in detail, defeating the main object of the bulletin, and making newspapers reluctant to reprint it.

Before any additional labor is imposed in the preparation of the crop bulletin by possible improvements, it must be remembered that these bulletins are generally very rapidly prepared. Their value depends to a great extent on the promptness of issue. In North Carolina the crop bulletin appears on Monday, which has been found to be the best day. The preparation begins early in the morning, the copy is in the hands of the printer by noon, and the entire edition of 1,800 copies is mailed by 6 p. m. During the five hours limited to preparation from two to four hundred crop reports must be read and considered. At Raleigh we have neither the time nor the facilities for the preparation of rainfall charts.

I believe that it would increase the value of the crop bulletins to publish rainfall reports from a larger number of stations, and a supply of, say 50, rain gauges might be issued to each State by the Weather Bureau for the use of selected crop correspondents.

Formerly a detailed map of the State, in colors, was printed on the back of the North Carolina crop bulletin, and was considered an advantageous feature, but the expense was found to be too great.

Form No. 1053, meteorological, used by crop correspondents in forwarding their reports is perfectly satisfactory. Form No. 1054, request for special information, should also be in the shape of a postal card, which would make it easier to handle and lead State weather service officials to use it more frequently. A far better plan of collecting data from crop correspondents would be to establish subordinate collecting centers, say at each county seat. Let the crop correspondent at the county seat receive reports from subcorrespondents throughout the county, summarize them, and mail his county summary to the central office. In most cases all the county summaries could probably be printed in the crop bulletin. In North Carolina under this system there would be only 96 county reports to consider instead of several hundred individual crop reports.

The best form for the publication of the crop bulletin has naturally been selected by most States, a single page, with first a general summary of the weather crop conditions for the State, then for the different districts, followed by a selection of the remarks of special crop correspondents.

The public press will always furnish the best means for distributing the information contained in crop bulletins. Although the edition of the North Carolina bulletin numbers only 1,800 copies, it reaches at least from 20,000 to 30,000 readers through the daily and weekly newspapers, of which 65 reprint the bulletin in whole or in part. Copies are also sent to 365 post-offices, where they are displayed on suitable bulletin boards for the benefit of the public.

Nothing proves more conclusively the value of the weather crop information published by the State weather services than the steadily increasing demand for these bulletins. The disinterested source from which the information emanates vouches for its accuracy. Outside misrepresentation of crop conditions becomes impossible. The information concerning the current condition of crops is alike valuable to agricultural and commercial interests. It places farmers on an equal footing with dealers who purchase their products, by enabling them to estimate probable yields and to judge whether they are receiving fair prices for what they have to sell. Boards of trade, boards of agriculture, chambers of commerce, and similar bodies all find the information contained in the crop reports of the greatest value.

3. MONTHLY PUBLICATIONS OF STATE WEATHER SERVICES.

I cordially approve of the form of publication adopted by some of the best State weather services, in which an endeavor is made to make the monthly reports of interest to other than specialists by including popular articles on topics related to meteorology and climatology. The Iowa report is a notable example. But I am decidedly opposed to advertisements of any kind appearing in official publications. I have observed advertisements in weather service bulletins which, to say the least, were in very bad taste, and tended to lessen the dignity of the scientific work in which we are engaged. In those cases where the issue of the monthly bulletins can not be secured in a satisfactory form without the assistance of funds obtained from advertisements, the reports should be printed by the national Bureau, as suggested by Mr. F. P. Chaffee.

The monthly publications of the North Carolina weather service naturally take the form of the bulletins of the experiment station, of which the weather service is considered a division.

Promptness of publication is very necessary, as tending to keep up the interest of

voluntary observers, besides making the information available to the public as soon as possible. Monthly reports should not be delayed beyond the 15th at the latest.

Uniformity in style of publication, though it might be desirable, is probably not practicable. I think it would be a good plan, as adopted by the North Carolina service, to bind up with the annual report the twelve monthly bulletins for the year, so that one volume will contain all the known data for the year.

With reference to the preservation in convenient form of the most important data from voluntary observers' records, I would suggest that the Weather Bureau issue record books like that which has been employed for many years by this service. A volume large enough to contain records from all stations for five years is used. Each page, large enough for twelve reports from two stations, is ruled on one side with columns for pressure, temperature, rainfall, wind, weather, etc., and on the other with spaces for entering miscellaneous phenomena, such as dates of thunderstorms, frosts, etc., and remarks by voluntary observers. All the known meteorological data for any station are thus conveniently arranged for reference. The reports of voluntary observers, after the sums and means have been verified, are first entered into this record book, from which the monthly bulletin is afterwards made up. A sample page of the book is inclosed.

4. DISTRIBUTION OF FORECASTS, VALUE OF LOGOTYPE SYSTEM, ETC.

The return to the method of telegraphing forecasts daily to displaymen instead of conditionally is unquestionably a great improvement, has renewed the interest of displaymen and increased the demand for the forecasts. The flags will be more promptly and carefully displayed. I am of the opinion that the display of the weather-signal flags in the cities is unsatisfactory and not worth the cost of the flags. People prefer to read the weather summary and forecast, and generally consult the nearest map for that purpose. The flags should be displayed only for a short time in the afternoon of one day to indicate the weather for the next day, and should be lowered about sunset. The display of flag signals may still be useful in the country, though eventually the wide distribution of card forecasts by mail should entirely displace it.

The logotype system of distributing forecasts I consider highly satisfactory and destined to supplant all other modes of disseminating weather forecasts until the telephone comes into more extended use. I think, however, it is better to secure the cooperation of postmasters rather than displaymen, and recent endeavors in that line in North Carolina have been very successful.

In view of the ever growing wider dissemination of weather forecasts is it not important that the people should properly understand the nature and use of the forecasts and how to estimate their worth? Although meteorology has developed rapidly during the past thirty years, especially in the line of weather forecasting, knowledge of the subject has not spread among the masses of the people in proportion to its importance in the everyday affairs of life. It is not generally understood that all the manifold and apparently capricious changes in the weather follow definite laws. Too many people still place reliance on the weather data contained in almanacs, on local weather proverbs of no real value, and upon the humbug predictions for months in advance made by certain notorious impostors in this country and in Canada, whose statements are based upon supposed influences of the stars, and are purposely worded so obscurely that they may be considered verified by any kind of weather. Surely, by this time it ought to be well known that none of the heavenly bodies have a perceptible influence on the weather, that there are no equinoctial storms, and that it is not necessary to wait for the wane of the moon before planting.

If the Weather Bureau is to reach the full measure of its value to the people the erroneous ideas still prevailing, especially among our farming population, must be eradicated. There is great need of popular information on the subject. The daily

weather maps have been extremely useful in this line, but I will venture to say that many who receive the map do not understand it. I remember hearing a very intelligent gentleman remark, pointing to a long curved isobar on the weather map, "What a strange way for the wind to blow."

In my opinion, nothing would more increase the interests of the people in the weather forecasts and prove their value than the publication by the Weather Bureau of a popular bulletin on the subject: "How weather forecasts are made, and how they may be utilized."

The subject should be presented in a nontechnical style, and could be made very interesting. It should contain an explanation of the elements of meteorology, and a brief description of the instruments in common use. The operations of the Weather Bureau should be explained, what an observation consists of, how the information reaches Washington, and how the maps are made. A chapter should explain the meaning of the terms "high" and "low," "cyclone" and "anticyclone," the conditions of the weather connected with each, the paths of storms crossing the United States, and should be liberally illustrated with maps and samples of forecasts made at the time. A collection of various methods of utilizing forecasts in agricultural interests should be given—for instance, the methods of protecting vegetation from frost, use of smudge fires, flooding of cranberry fields with water, etc.

Such a bulletin would stimulate interest everywhere, and greatly enlarge the sphere of usefulness of the Weather Bureau and State services.

As I have already exceeded reasonable limits in this communication, I will say but a few words more on the last two subjects before the convention.

I think the inspection of voluntary stations highly important. It is suggested that the regular inspectors of the Weather Bureau should visit voluntary observers at stations along their routes when inspecting stations of the Weather Bureau.

The importance of equipping voluntary observers with shelters lies in the fact that uniformity of exposure is thereby secured, making observation taken everywhere comparable. Differences of opinion as to the size of shelter to be adopted, elevation above the ground, etc., should be laid aside, and nothing could be better than the adoption of the style of shelter recommended by the committee on instrument shelters appointed at the first convention of State weather services in 1892. The report of the committee was signed, I believe, by Messrs. W. L. Moore and J. W. Smith.

With reference to special investigations which can best be undertaken by State weather services, I think none could be more valuable than detailed investigations into the relations of climate to the growth of various crops, for which work State weather services have every facility. Prof. P. H. Mell's report on the climatology of the cotton plant (Bulletin No. 8, of the Weather Bureau) is an indication of what might be accomplished in that line. The great amount of routine work done at most State weather service centers will seriously interfere in most cases with the undertaking of such special investigations. This is the most important subject before the convention, and I hope it will be thoroughly discussed.

REPORT OF COMMITTEE APPOINTED TO INVESTIGATE THE SUBJECT OF STAMPING WEATHER FORECASTS ON MAIL MATTER.

MONTGOMERY, ALA., *November 12, 1895.*

SIR: As chairman of the committee appointed by the Association of American State Weather Services, in convention at Indianapolis, Ind., for the investigation into the merits and practicability of the "post-mark logotype" system as suggested by me at the recent convention, I have the honor to submit the following:

Capt. T. F. Townsend, director of the Pennsylvania State weather service, and Mr. S. W. Glenn, director of the South Dakota service,

were also appointed members of this committee, but owing to the great distances intervening there has been an inability on the part of the committee to take any concentrated action in this investigation, and it was decided that individual reports be rendered. The report of Captain Townsend will be found among the inclosures; that of Mr. Glenn was evidently lost in the mail, as is evidenced by inclosed letter from him, dated 7th instant. However, he has been requested to forward a copy of his report, which will be transmitted immediately on its receipt.

A circular was sent to the directors of the various State weather services and officials in charge of the Weather Bureau offices in some of the large cities. The circular was issued with the intention of gaining a consensus of opinion as to the merits and demerits of the proposed system with a view to perfecting the same as far as possible before report should be made, and not with a view to forestall any future action by the Weather Bureau. A majority of the replies favor the suggestion, while a few offer objections, which, it is thought, could be overcome with but little difficulty. These objections are nearly all relative to the legibility of the postmark stamp. The only way to either affirm or refute this objection is by giving the system a trial, and it is thought that the postmasters and clerks would be more cautious in stamping when they know that their stamp is to convey other information besides the date of receipt of the letter.

Some of the officials to whom the circular was sent gave the matter to the local press for publication. This was done not through request or desire of mine, and while the kindly spirit which prompted this action is fully appreciated, it would have been preferable to have abstained from publishing it until after the matter was officially acted upon.

It appears from a letter received from the director of the Wisconsin State weather service that the postmaster at Racine, Wis., having his attention called to the newspaper comments on the proposed system, has given it a practical test, and that he has communicated with the Chief of the Weather Bureau and Postmaster-General asking permission to inaugurate this system of distributing weather information. This action of the postmaster at Racine, while demonstrating the feasibility of the system, has hastened the rendering of my report on this matter. It was my intention to wait until all possible information could be gathered before making report, but for the above reason it was thought best to bring it to the attention of the Weather Bureau.

Some of the advantages of such a system of distribution of forecasts are set forth in the circular, a copy of which is inclosed, and it is hardly necessary to dwell upon its many advantages and its many adaptations to distributing weather information and special warnings.

I have not procured a practical working stamp illustrating its mechanical construction, as such was deemed unnecessary at this stage of the matter.

Captain Townsend in his report, inclosed herewith, makes a good suggestion, which is that if this plan of distribution is adopted the forecasts be telegraphed to railway mail clerks, who can stamp them on cards to be deposited in the respective pouches to be distributed to postmasters along balance of their routes, who can distribute their information by the postmark system. Thus one telegram would convey the initial information to a number of distributing postmasters, many of whom might not have telegraphic communication.

I have to report that the suggestion is considered practical, and feel sure that practical tests will develop its merits.

It is thought that should the system be put in extensive use that the cost of stamps might be arranged with the Post-Office Department, so that it and the Weather Bureau would each bear their share of the expense.

After a thorough consideration of the matter I recommend as follows:

First. That this matter be referred to the Chief of the Weather Bureau for his consideration, with the recommendation that the system suggested be adopted and that the necessary cooperation of the Post-Office Department be secured.

Second. That the system be first put in operation in such towns or cities as are already forecast display stations and have a carrier delivery, and that the forecasts be telegraphed to the postmasters of such places, who, if not the displaymen, can furnish the latter a copy of the forecasts.

Third. Should the system prove successful, that the forecasts be telegraphed to railway mail clerks, who will distribute them to postmasters, who will in turn stamp them on mail delivered.

Fourth. That if this system is adopted, it be thoroughly advertised in the press of the country, also through the Official Postal Guide, and that large cardboard *bulletin boards describing the system be furnished postmasters for display in their offices.

In conclusion, I beg to say that should the Chief of the Weather Bureau consider the suggestion worthy of adoption, it would afford me pleasure to aid in any manner whatsoever the successful operation of such a system of forecast distribution.

Very respectfully,

F. P. CHAFFEE,
*Director Alabama State Weather Service,
Chairman of Committee.*

Maj. H. H. C. DUNWOODY,
*President American Association of
State Weather Services, Washington, D. C.*

PHILADELPHIA, PA., November 6, 1895.

DEAR SIR: As a member of the committee appointed to investigate and report upon the practicability of distributing forecasts in the rural

districts by the "postmark logotype" system, suggested by you at the recent State Weather Service convention, I submit the following:

Owing to the impossibility of giving a practical test of the proposed system, conclusions relative to its merits must necessarily be largely theoretical. These, however, can be based on known existing conditions, which must be used in carrying out the scheme.

The main groundwork for the suggested plan is already provided for by the Government in its prompt and rapid delivery of the mails throughout the rural districts, and with a slight extension of the liberal policy already pursued by the Post-Office Department in its cooperation with the Weather Bureau in disseminating its forecasts, together with suitable logotype stamps for the distributing postmasters and an organized system for furnishing them with the necessary information, the plan will be complete in every detail.

The forecasts to be of value must be the very latest, and without an effective and economical means for placing them in the hands of the postmasters the proposed scheme would be incomplete and objectionable.

This can not be done by wire to each postmaster because of the lack of facilities and the great expense that would attend it. Neither could it in many cases be done by cards from the offices of the Weather Bureau, as the mails frequently leave before the forecasts are issued; but it can be done at a comparatively small expense by wiring the forecasts to railway mail clerks at proper points along their lines, and have them stamp the forecasts by logotype on cards addressed to the various postmasters along the balance of their route, and then place the cards in their respective pouches so that the distributing postmasters will receive the latest information with their mail.

In this manner many post-offices can be reached which have neither telegraphic nor telephonic facilities.

Additional means of communication will naturally suggest themselves when the scheme is once in operation. While, perhaps, one general rule can be given, some districts may require special arrangements which can be worked out by those having the work in charge.

With the forecast for distribution in the hands of the postmaster on the arrival of his mail pouch, I see no reason why he can not, with a suitable appliance, rapidly stamp the forecast on the back of each letter in connection with its date and time of receipt. The wording must, of course, be in a concise form, particularly during its tentative stage.

To summarize, I believe the distribution of forecasts by the "post-mark logotype" system perfectly feasible, and one that will be appreciated by the general public. I therefore recommend its favorable consideration.

Very respectfully,

Mr. F. P. CHAFFEE,

*Director Alabama State Weather Service,
and Chairman of Committee.*

T. F. TOWNSEND,
Observer in Charge.

HURON, S. DAK., *November 7, 1895.*

DEAR SIR: Referring to my communication of 29th ultimo, relative to the duplication of forecasts on mail matter, I beg to state that I believe figures indicating the date would be more distinct and more readily noticed by the public if they were placed around the ordinary postmark. I am still of the opinion that the word "to-morrow" and the forecast should find place in the stamp proper and not in any separate attachment, as indicated in your illustrations.

Since writing you I have noticed closely the manner of using the receipt stamps in the office here, and the liability of any attachment on the outside of the regular style of stamp coming loose and proving a source of annoyance to the stamping clerk is very great.

I would be glad to know the result of your correspondence with the stamp manufacturers, as they are no doubt in position to furnish something substantial.

I realize that my suggestion would necessitate the substitution of new stamps complete by the Post-Office Department, but am unable to see how any attachment to the stamps now in use, except those operated by electricity in the large cities, would work satisfactorily.

Yours, hoping for success,

SAM. W. GLENN.

Mr. F. P. CHAFFEE,

*Director Alabama State Weather Service,
Montgomery, Ala.*

Bulletin No. 19.—W. B., No. 97.

Price 15 cents.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

REPORT
ON THE
RELATIVE HUMIDITY
OF
SOUTHERN NEW ENGLAND
AND OTHER LOCALITIES.

PREPARED UNDER THE DIRECTION OF

WILLIS L. MOORE,
CHIEF OF WEATHER BUREAU.

BY

ALFRED J. HENRY,
CHIEF OF DIVISION.



WASHINGTON:
WEATHER BUREAU.
1896.



CONTENTS.

	Page.
Relative humidity defined	7
Aqueous vapor:	
sources of	7
evaporation and condensation of	7
distribution of, through the atmosphere	8
Observing stations	8
Observations, accuracy of	9
Relative humidity:	
general remarks on	10
New England group	10
New England group as compared with Mobile	11
New England and Mobile as compared with Piedmont Plateau	11
northern central New York	12
extreme monthly variation of	13
diurnal variation of	13
influence of the winds on	14
accidental variations of	16
individual cases of low	16
inside and outside of buildings	16
Manufacture of cotton, climatic influences affecting	17
Lancashire, climate of	18
India, climate of	18

TABLES AND PLATES.

Table	I. Monthly mean relative humidity	19
	II. Monthly mean relative humidity at 7 a. m., 2 and 9 p. m. .	20
	III. Mean daily range of relative humidity	20
	IV. Greatest change in relative humidity in eight consecutive hours	21
	V. Lowest relative humidity, average of	21
	VI. Lowest mean daily relative humidity for twenty-four and forty-eight consecutive hours	22
	VII. Monthly mean temperature	22
	VIII. Monthly mean precipitation	23
	IX. Monthly mean cloudiness	23
Plate	I. Typical curves of relative humidity.	
	II. Averages at 7 a. m., 2 and 9 p. m., January and July.	
	III. Diurnal variation.	
	IV. Sketch map of English stations.	



REPORT ON THE RELATIVE HUMIDITY OF SOUTHERN NEW ENGLAND AND OTHER LOCALITIES.

The relative humidity of the air is merely a convenient term for expressing comparative dryness or moisture. When the air is completely saturated with aqueous vapor its relative humidity is said to be 100 per cent; when it contains but three-quarters of the amount of vapor necessary for complete saturation, the relative humidity is said to be 75 per cent.

The aqueous vapor in the air is derived primarily from the evaporation of water from the ocean and from the soil, streams, and vegetation of the earth's surface.

The quantity of water that can exist in the form of vapor is determined by the temperature of the air in which evaporation takes place. For example a cubic foot of air at a temperature of 32° F., can contain no more than 2.11 grains of water in the form of vapor; if, however, the temperature of the air be raised to 48°, 64°, and 80°, it can then contain 3.80, 6.56, and 10.93 grains of water vapor at the respective temperatures. It will be observed that the increase in the amount of water vapor is not proportional to the increase of temperature; thus at a temperature of 64° the air can contain more than three times as much vapor as at 32°; at 80° nearly four times as much as at 40°. With a clear understanding of this important fact, it becomes apparent that the relative humidity depends very greatly upon the temperature, as will be referred to again at greater length.

The process of evaporation may be regarded as an attempt on the part of nature to maintain the vapor atmosphere in perfect equilibrium. The latter is being constantly disturbed by other natural phenomena, such as the formation of cloud and fog, the precipitation of moisture in the form of rain, snow, etc. There are several methods of changing water vapor to liquid form, thus diminishing the amount of vapor present in the air. The principal one consists in lowering the temperature of the vapor and the other bodies in contact with it until the point of saturation has been reached. The simplest illustration of this method is found in the formation of dew. During the warm hours of the day the solid particles of the earth's surface proper, together with the bodies of many organic forms, are raised to a temperature much higher than that of the surrounding air. While in this condition, the water vapor present in the air will not condense upon them even if the temperature of the air be cooled to the point of saturation. The same substances, however, which

warmed up very fast in the daytime, cool at an equally rapid rate during the night, and soon become cooler than the surrounding air. As soon as they are cooled to the temperature of saturation, vapor molecules begin to condense upon their surfaces.

The relative humidity during the cycle of events just mentioned sinks rapidly with increase of temperature during the heated part of the day, because the higher the temperature the greater the capacity for moisture, and also partly because the surface evaporation is greatly weakened as the day advances. With the approach of night the temperature falls and the relative humidity increases, reaching the highest percentage of the day approximately at the time of lowest temperature.

The relative humidity of a place, whether constant or variable, depends greatly upon the daily and seasonal temperature changes, the amount of cloudiness, the frequency and amount of precipitation, etc. Abundant sunshine and intense radiation are invariably associated with low relative humidity, and marked variation between day and night; on the other hand, excessive cloudiness and a small range of temperature conduce to a high degree of relative humidity, with slight changes from day to night.

The distribution of aqueous vapor through the atmosphere is chiefly controlled by the movements of the air in its local and general circulation. If the atmosphere were perfectly quiet and everywhere of a uniform temperature, no condensation would take place, while the aqueous vapor would be equally diffused in all directions, satisfying the law of diffusion of gases. But since such is not the case in nature, it follows that the amount of aqueous vapor in the air at any place must vary with changes both in local atmospheric conditions and the season of the year. And while these variations may be of considerable moment on individual dates or in a particular season, yet in the long run the average of accumulated observations for any region may be safely used to show the distinctive characteristics of that region.

The results of a comparison of the relative humidity of the southern shore of New England with that of certain other localities in the United States and abroad are given on the following pages.

The stations selected.—Choice of stations in New England, as also in other regions, was necessarily restricted to those points at which observations were made at the same hours and on a uniform plan. New Bedford and Woods Hole, Mass., Newport, R. I., and New London, Conn., were selected to represent the coast region of southern New England; Mobile, Ala., was chosen as a point on the Gulf Coast most nearly resembling in environment the New England stations; Atlanta, Ga., and Charlotte, N. C., were selected as representative of inland stations of moderate elevation on the Piedmont Plateau; and

Augusta, Ga., and Wilmington, N. C., as representative of the tide-water stations of this region. Oswego and Utica, N. Y., were also selected on account of certain distinctive climatic features, as will appear subsequently.

The elevation above sea level of Atlanta is 1,050 feet; Charlotte, 725 feet; Utica, 537 feet; Oswego, 304 feet, and Augusta, 128 feet. The remaining stations—New Bedford, Woods Hole, Newport, New London, Wilmington, and Mobile are practically at sea level.

The thermometers were exposed at the following heights above ground:

New Bedford.....	6 feet.
Woods Hole	7 "
Newport	19 "
New London	29 "
Oswego	34 "
Utica	2 "
Charlotte	34 "
Wilmington..... { January, 1878, to November, 1879	26 "
{ November, 1879, to December, 1880.....	62 "
Atlanta	78 "
Augusta..... { January, 1878, to December, 1878.....	28 "
{ January, 1879, to December, 1880.....	19 "
Mobile.....	32 "

The observations.—The observations used, with the exception of those at New Bedford and Utica, were made by Signal Service (now Weather Bureau) observers, at 7 a. m., 2 p. m., and 9 p. m., local mean time, during the years 1878, 1879, and 1880. The single-louvre window thermometer shelter was in use during that period, and artificial ventilation was not resorted to, as at present. The relative humidity was deduced from readings of the wet and the dry bulb thermometers by the formula given in Guyot's *Meteorological and Physical Tables*, published by the Smithsonian Institution.

The observations at New Bedford were made by Mr. Thomas R. Rodman, voluntary observer for that place, and one of the most careful and experienced of the voluntary observers cooperating with the Weather Bureau. Mr. Rodman recorded the readings of both wet and dry thermometers, but did not compute the relative humidity, the necessary computations being made in the Central Office of the Weather Bureau.

The Utica observations were made by Mr. Thomas Birt, Voluntary Observer, Weather Bureau, during parts of the years 1888, 1889, 1890, and 1891. The series is much broken and is also incomplete, there being no 2 p. m. observation. Mr. Birt's thermometer shelter was fastened to a tree 27 feet in the rear of his house and 2 feet above ground.

Accuracy of observations.—It should be remembered that the relative

humidity of the air can not be determined with the same precision as its temperature or pressure. It is doubtful, indeed, whether the most accurate observers, working under identical instructions, can arrive at results agreeing within 1 per cent at temperatures above freezing, and even greater differences will occur at temperatures below freezing.

General remarks.—The term "relative humidity," as stated at the outset, is merely a comparative expression of a physical fact, viz, the proximity to saturation of the air at a given moment, and conveys no idea of the absolute amount of moisture in the air. The latter is relatively constant, and follows more or less closely the seasonal temperature, the amount contained in the air at any point being dependent upon the temperature of the place and its situation with reference to large bodies of water.

Over the ocean the mean daily relative humidity is, on the average of the year, between 80 and 90 per cent; over the land it varies from the dryness of the desert, 50 per cent and less, to 90 and 95 per cent at points where the conditions are most favorable to complete saturation. Generally it is greatest in winter and least in summer.

New England group.—The topographic features of the stations comprising this group are not sufficiently divergent to effect the humidity conditions to a marked extent. The station at Woods Hole is situated on a narrow strip of land not more than five hundred feet from the waters of Little Harbor on the one side and Great Harbor on the other. The adjacent land is low and flat, there being no portion of it within a mile of where the observations were made above one hundred feet in elevation. These conditions are all favorable to a high and fairly constant degree of relative humidity; in fact, at no other station are the conditions so favorable for a maximum degree of saturation as at Woods Hole.

It would appear from an examination of the figures in Table I that the percentage of relative humidity at New Bedford is considerably higher than at any other station. Further examination, however, shows that it is only in the colder months of the year and at the morning and night observations (see Table II) that the differences between New Bedford and the remaining stations are pronounced. A careful consideration of the New Bedford observations leads to the conclusion that the conditions shown to exist at the morning and night observation hours in cold weather are more or less artificial, due to errors in observation or some local effect not heretofore understood or explained.

The general characteristics of the New England group may be summed up as follows:

The air is about three-quarters saturated with water vapor on the average of the year. The lowest monthly average is about 70 per cent; the highest, 80 per cent. The greatest change from one

month to another is about 6 per cent from September to October. At individual stations the greatest variations are: New Bedford, 7 per cent, March to April; Woods Hole, 6 per cent, September to October; New London, 6 per cent, September to October; and Newport, 5 per cent, September to October.

August and September are the most humid months; April and May the driest. The distribution of relative humidity throughout the year is graphically shown on Plate I.

New England compared with Mobile.—Mobile, on account of its environment, was selected as a probable point in the Southern States where the relative humidity should agree quite closely with that of the southern shore of New England. That it *does* so agree, so far as the general distribution is concerned, can easily be seen from the curves on Plate I, and the numerical values in Table I. The only notable difference is in the time of occurrence of the maximum degree of saturation, viz: in winter instead of in July and August as in New England. There is, however, a secondary maximum in the months of chief maximum in New England, August and September. While the general features of the relative humidity at both Mobile and southern New England are in close accord, considering only the monthly averages, there is a well-marked difference in the diurnal variation as will be shown later.

New England and Mobile as compared with Piedmont Plateau.—The curves representing the annual march of relative humidity on the Piedmont Plateau and south Atlantic Coast are essentially different from those of southern New England and Mobile. There is a remarkable decrease in the relative humidity in February as compared with December and January, and the fall continues until June, when the lowest limit is reached. The relative humidity then increases to a maximum in August, decreasing again to a second minimum in November. Although the inland stations of this group are rather widely separated, the monthly averages are in close accord and indicate clearly (a) that the variations from month to month are greater than on the southern New England or Gulf coasts; (b) that the greatest extremes of dryness are reached in the late winter and spring months, February to May, inclusive, and (c) that the air is considerably drier on the average than on the Gulf Coast or southern New England.

The differences here noted are chiefly those due to geographic location with respect to large bodies of land or water. The coast stations partake more or less of the climate of the ocean, particularly if situated so that the prevailing winds are from the sea. In the summer season the winds of southern New England are chiefly from the south and southwest, thus tempering the climate of the land and insuring a uniform supply of moisture. The climate of New England, the year round, is noted for its changeableness, its great ranges of tem-

perature, and the alternating of clear and cloudy skies at short intervals. The great atmospheric disturbances which are continually moving across the country, pass directly over or near its borders. Each cyclonic storm causes an increase of temperature and more or less cloudy weather, and a varying period of complete saturation.

The climate of the Piedmont Plateau and south Atlantic and Gulf coasts differs from that of New England in that the weather conditions are more settled; the number of cyclonic storms, as compared with those of New England, is in the ratio of about one to three. The cloudiness is less, as is also the number of rainy days, although the rainfall is from 10 to 15 per cent greater. The winds of summer, except on the immediate coast, are warm and relatively dry, as compared with the southerly winds so prevalent on the southern coast of New England.

The low relative humidity of the spring and early summer months at the inland stations of the South is in strong contrast to the conditions that obtain on the coast. Wilmington though 8 or 10 miles distant from the sea, shows the influence of the water very plainly.

Northern Central New York.—The causes which contribute to a more or less uniform condition of relative humidity on the sea coast are also effective in producing a fairly constant degree of humidity near the Great Lakes, notably in northern-central New York, over a region extending eastward through a portion of the Mohawk Valley.

The distinguishing characteristics of this part of the State are: (1) a large number of rainy days, although the amount on each day is small; (2) excessive cloudiness, and (3) a temperature modified by proximity to the lakes. The cloudiness is considerably greater than that of New England, and much greater than that of the South. The cloud layer serves as a screen to protect the earth from excessive insolation by day and radiation by night. The temperature is, therefore, more uniform than it would otherwise be, and the changes in relative humidity correspondingly less. Unfortunately, the observations of relative humidity for this region are quite meagre, unless we accept those made at Oswego or Rochester. The series at Utica is incomplete, there being no midday observation. At the morning and evening hours, however, the relative humidity appears to be quite constant, and the air is more nearly saturated than at Oswego directly on the lake. The Mohawk Valley, in which Utica is situated, is a deep depression between the highlands of northern and central New York. The prevailing winds are almost exclusively in the direction of the valley, viz: easterly and westerly. The valley winds at night are almost invariably cool and, consequently, relatively moist. The 2 p. m. observation at Oswego shows that in the warmer months of the year the midday humidity is not greatly different from that of southern New England. By reference to Table VII it will be seen

that the monthly mean temperatures of Utica and Oswego are practically the same. It is therefore reasonable to assume that their humidities are not widely different.

Extreme monthly variation.—The extreme variation, at all stations thus far considered, during the year is as follows:

(Greatest monthly average minus (—) least).

Woods Hole	12 per cent
New Bedford	10 per cent
Newport	7 per cent
New London	6 per cent
Oswego	8 per cent
Charlotte	17 per cent
Wilmington	6 per cent
Atlanta	17 per cent
Augusta	10 per cent
Mobile	8 per cent

The foregoing statements include the main points of difference, considering only the monthly means.

Diurnal Variation.—Each monthly mean should be considered as a composite made up of the means at 7 a. m., 2 and 9 p. m. The diurnal variation of relative humidity in its simplest phase, is as follows: The maximum takes place during the early morning hours, and the minimum from 1 to 4 p. m., being simply the inverse of the daily temperature changes. The mean relative humidity at 7 a. m., in the winter months, is considerably above the mean of the twenty-four hours, but with the approach of summer the difference becomes less. The mean at 2 p. m. represents fairly well the lowest point reached during the day, while the mean at 9 p. m. is greater than the daily mean.

Differences as shown by means at 7 a. m., 2 and 9 p. m.—The means at 7 a. m., 2 and 9 p. m. have been calculated for each of the stations examined, and the results will be found in Table II and in diagrammatic form for January and July on Plate II.

It is at once apparent that while the monthly means at any two places may agree within a fraction of one per cent, there may be considerable difference in the daily range; thus the monthly means of Newport and Mobile for March are identical—72.3 per cent—yet the range at Mobile is from 85 per cent at 7 a. m. to 55 per cent at 2 p. m., while at Newport the range is from 77 per cent at 7 a. m. to 65 per cent at 2 p. m. While this is an extreme case it illustrates very forcibly the main point of difference between the humidity regime of the two places. Table III (from which the foregoing illustration was drawn) was prepared to show the extent of the variation from 7 a. m. to 2 p. m., or from 2 to 9 p. m. for all stations. (See also Plate III.)

From these data it will be observed that the relative humidity at Woods Hole is more constant than at any other station. It is like-

wise the station most exposed to the influence of the ocean. The greatest variations are found at Augusta, Wilmington and Mobile, in the order named. The variations at New Bedford are believed to be unduly large, and they have not been considered as representing southern New England.

Influence of the winds.—The distribution of relative humidity throughout the day at the New England stations differs again from that of the southern stations on account of the prevailing winds. On the southern coast of New England the prevailing winds of the warmer months (especially at 2 and 9 p. m.) are from the south and southwest, directly from a water surface cooler than the land. As a result the relative humidity during the warmer hours of the day is kept at a figure not far from the average at 7 a. m., while at 9 p. m. the amount is even greater than in the morning, thus reversing the conditions which obtain at interior stations.

The prevailing winds of New England in winter are from the northwest. The northwest wind is a dry wind throughout the year and tends to maintain the relative humidity, during its prevalence, at or near the lowest limit of the year.

The wind system of Mobile is somewhat different from that of New England, as will be seen by the table which follows. The percentage of northerly winds at Mobile is much greater than at Newport. In winter the north wind at Mobile is relatively drier than the same wind in New England, particularly during the warmest part of the day. In summer the reverse is the case during the morning and evening, but the north winds of the warmest portion of the day are relatively drier than those of New England. The winds from water surfaces at Mobile do not differ greatly from similar winds on the southern shore of New England.

The winds at inland stations are less regular; that is to say, they do not blow from any one quarter with the regularity observed on the sea coast. They are of course drier than the coast winds.

The relative humidity of the winds varies greatly with the hour of the day, the season of the year, and the geographic location of the place. The following table shows the relative humidity of the various winds for January and July at four stations only.

Relative humidity of the various winds for January and July.

(The number of winds is given in the column headed "W.")

JANUARY.

Direction.	Newport.						Charlotte.					
	7 a. m.		2 p. m.		9 p. m.		7 a. m.		2 p. m.		9 p. m.	
	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.
N	14	81	7	73	8	77	10	82	8	67	19	74
NE	7	71	6	79	5	77	28	80	16	70	18	72
E	4	92	4	85	4	90	9	85	14	62	14	73
SE	2	95	3	71	4	88	3	95	5	58	5	74
S	2	96	4	58	9	88	8	88	10	62	10	82
SW	20	88	23	74	17	75	16	82	21	58	18	72
W	22	70	21	54	25	65	9	88	11	56	6	79
NW	19	70	23	56	18	66	8	79	8	58	11	56
C	3	71	1	65	3	74	2	100	.....	.....	1	87

Direction.	Wilmington.						Mobile.					
	7 a. m.		2 p. m.		9 p. m.		7 a. m.		2 p. m.		9 p. m.	
	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.
N	14	78	10	60	7	69	28	82	27	54	21	66
NE	24	81	12	55	13	80	4	71	4	41	5	76
E	4	87	8	56	12	79	5	84	4	57	3	76
SE	12	79	10	62	5	81	5	95	7	77	4	86
S	3	61	6	87	6	88	23	97	37	75	36	92
SW	14	82	15	51	19	77	4	94	3	58	6	84
W	11	95	12	60	7	67	1	69	5	52	2	78
NW	10	76	16	45	11	61	9	82	6	55	6	73
C	10	86	3	62	12	81	14	98	.....	.....	9	85

JULY.

Direction.	Newport.						Charlotte.					
	7 a. m.		2 p. m.		9 p. m.		7 a. m.		2 p. m.		9 p. m.	
	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.
N	12	77	2	66	4	71	7	65	5	61	6	70
NE	8	73	4	54	4	71	11	77	4	49	8	74
E	2	92	6	68	2	76	5	79	10	50	1	75
SE	2	92	6	65	6	83	4	81	5	58	7	68
S	12	87	19	65	18	82	8	85	8	58	17	70
SW	34	84	44	69	44	86	11	79	12	51	6	66
W	3	72	3	62	4	68	10	71	12	49	4	81
NW	17	71	6	47	4	72	5	64	6	43	5	57
C	3	84	.....	.....	7	80	1	95	.....	.....	2	56

Direction.	Wilmington.						Mobile.					
	7 a. m.		2 p. m.		9 p. m.		7 a. m.		2 p. m.		9 p. m.	
	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.	W.	R. H.
N	2	86	1	44	2	86	23	84	7	61	12	86
NE	22	80	6	64	6	78	5	86	6	58	3	86
E	10	82	16	59	15	70	7	83	8	63	8	77
SE	3	75	17	55	11	79	6	81	11	60	7	84
S	5	88	24	62	24	74	13	80	38	59	25	78
SW	25	85	15	64	25	83	11	84	10	70	20	78
W	15	79	8	50	1	86	14	82	8	74	9	76
NW	3	88	5	54	2	80	9	81	3	73	7	89
C	8	86	1	75	6	79	5	86	1	64	7	83

The foregoing table presents a variety of detail that the reader may study for himself. The broader generalizations suggested by the data, are as follows: (a) The northwest wind is the dry wind at almost all stations and for all seasons, an exception being noted in the case of Mobile for 9 p. m. of July. Here the winds from a northerly quarter are the relatively moist winds. A warm wind blowing over a cooler surface, or a wind that by any means loses a portion of its heat without the condensation of any of its moisture, becomes a relatively moist wind. (b) The winds from the sea are generally the more constant as regards vapor contents, a notable example being the southwest wind of the New England Coast. (c) A moist wind on the immediate coast does not necessarily carry its moisture a considerable distance inland; the contrary is sometimes the case; for example, the northeast wind at Wilmington in January, although almost direct from the sea, is relatively drier than the same wind at Charlotte, nearly 200 miles inland. This is probably an effect of the higher temperature at Wilmington during the winter months.

Accidental variations.—Thus far monthly means only have been considered. It is now proposed to look into the fluctuations due to sudden changes in temperature and other atmospheric conditions. In order to compare the sudden and marked changes in relative humidity, the observations were examined to find the greatest change, whether a rise or fall, from one observation to the next succeeding one, and the changes so found were tabulated and averaged. The averages are given in Table IV. The sudden changes are generally greater at the southern stations, except in July and August, when the changes in New England are greater than those at Charlotte and Atlanta, and about equal to those of the remaining southern stations.

Lowest relative humidity; individual cases.—Table V shows the averages of the lowest individual cases of relative humidity recorded each month of the years of observation. As in the case of the greatest range, the lowest values occur in the spring months and at the inland stations of the South. These data are important as showing the lowest limit of dryness reached in the respective sections. The degree of dryness that prevails at times for periods of twenty-four and forty-eight hours, is shown by the data of Table VI. Generally these periods of extreme dryness do not extend over two or three days.

Relative humidity inside and outside.—The ordinary thermometer shelter is generally placed on the roof of a building, or attached to a window facing the north, or failing these, is placed on a ground support at some distance from the building.

In applying statistics of relative humidity obtained from instrumental readings made in the open air in the ordinary thermometer shelter to inside conditions, it may be well to inquire, "What is the relation between the humidity inside of a building and outside of it?"

Beginning March 1, 1896, the relative humidity of the observers'

room, third and top story of the Weather Bureau building, was determined at the time of making the 2 p. m. observation. The room is heated by steam and fairly well ventilated. An open stairway leads to the halls below.

The average temperature of the room during March was 72°, relative humidity 32 per cent; the average outside air temperature was 32°, relative humidity 64 per cent. The outside humidity ranged from 38 per cent to complete saturation, 100 per cent; the inside from 24 to 57 per cent. The extreme variation from one day to another at the same hour was, outside 46 per cent, inside 24 per cent. The variations inside were on the average very much less than on the outside, as would be expected by reason of the uniform temperature inside. The March observations are fairly typical of a winter month when the conditions are most favorable for extreme dryness. When, however, the outside and inside temperatures approach each other, the relative humidities also become more nearly equal.

Thirteen observations have thus far been made in the present month (to April 22), with the following results: Outside temperature 68°, relative humidity 46 per cent; inside temperature 78°, relative humidity 37 per cent; ranges in relative humidity, outside, from 32 to 81 per cent; inside, from 25 to 44 per cent; greatest daily range, outside, 43 per cent; inside, 13 per cent.

From the 13th to the 21st mid-summer weather prevailed, the average temperatures inside and outside being 83.4° and 84.6°, respectively. The relative humidities during the same period were 40 and 41 per cent, respectively. The foregoing facts show, among other things, the importance of a uniform temperature whenever uniform humidity conditions are desired, and that outside hygrometric observations cannot be relied upon as giving true humidity values for the interior of buildings except when the temperatures, inside and outside, are practically the same.

Manufacture of cotton abroad; climatic influences affecting.—The manufacture of cotton is carried on in various parts of the globe and under widely different climatic influences. The oldest cotton producing country is India, where it has been grown and manufactured from time immemorial. Cotton fabrics were known in China before the Christian era, and early mention is made of the cultivation of the plant in Egypt, Asia Minor and in other countries bordering on the Mediterranean. The manufacture of cotton on an extensive scale, however, appears to have centered in and about Manchester, England, from an early period of the seventeenth century. The idea that the tendency to concentrate the cotton manufacturing industry in Lancaster was originally due to the advantage of climatic conditions, can hardly be entertained. To cheaper accommodations for carrying on the work, the lower wages of workmen, the proximity to rich coal fields, and

the advantages of water transportation must be ascribed the great development of the industrial arts that has made Manchester famous throughout the civilized world. Some of the causes that once operated to concentrate the industry in Manchester are now operating to distribute it to the outlying towns and villages. The town of Oldham, about 6 miles northeast of Manchester, at an elevation of 688 feet above mean sea level, is one of the most important seats of cotton manufacture in the world. Its importance is largely due to the fact that it is on the edge of the Lancashire coal field where the mineral is very easily obtained.

Lancashire, climate of.—It has not been possible to obtain statistics of relative humidity for either Manchester or Oldham, but sufficient data have been obtained from the reports of the Royal Meteorological Society for surrounding points in Lancashire, Derby, Cheshire, and Stafford (as shown on Plate IV) to arrive at a very close estimate of the conditions which prevail throughout Lancashire. The climate of Lancashire has no counterpart in the United States. The range of temperature is exceedingly small (see Table VII), the summers are cool, and there is little change from day to night. The rainfall is a little less than that of New England, but the number of rainy days is greater. The cloudiness is greater than in any portion of the United States, as is also the relative humidity. The latter is remarkably constant, on account of the even temperature and the extremely small daily range. It should be remembered, however, that the averages of relative humidity for English stations have been computed from but two, and in some cases but one, daily observation. They are not therefore strictly comparable with those of American stations, in which a midday observation has been included. As before stated, the capacity of the air for vapor increases very greatly with the temperature. At a temperature of 40° saturated air contains 2.86 grains of aqueous vapor per cubic foot; at *twice* that temperature (80°) a cubic foot contains nearly four times as much vapor, viz: 10.93 grains. The mean summer temperature of Oldham is not far from 58° ; at that temperature the capacity of the air for vapor is about one-third less than it is in southern New England, with a mean summer temperature of 68° . The amount of vapor sufficient to cause a high relative humidity at Oldham would, therefore, cause only a moderate degree of saturation at the temperatures which obtain in New England. The conditions which dominate the weather of Lancashire come chiefly from the Atlantic Ocean. In the United States the controlling influences come from the west, giving more or less of a continental character to the weather of the eastern seaboard.

India, climate of.—The extensive erection of cotton mills in Bombay, the Madras Presidency, and Bengal, within recent years, has caused the Lancashire merchants to fear the competition of India. The

climatic conditions of Bombay, Madras, and Dacca are shown in Tables I, VII, VIII, and IX.

The predominating features of Indian climate are the semiannual reversal of the wind system and associated phenomena. The figures given in the tables above named have been taken from Report on the Meteorology of India, 1890, John Eliot, M. A., Calcutta, 1892, to which the reader must be referred for further details as to the climatic phenomena of that country.

Attention is directed to the averages of relative humidity at Dacca, which place, it will be remembered, is famous for the exquisite texture of its muslins. The annual march is not unlike that of the Piedmont Plateau, except as regards the strength of the maximum during the southwest monsoon. The manufacture of cotton in India by native artisans is not confined to any particular locality, but is diffused throughout the central provinces and on both coasts under widely varying climatic conditions.

From the foregoing it would appear that thus far in the development of the cotton manufacturing industry little account has been taken of climatic conditions as affecting the quantity or quality of the output. It is also apparent that the relative humidity of the atmosphere depends not only on the absolute quantity of vapor present in the air, but also on the temperature which determines the point of saturation, and that these elements vary both as regards time and geographic situation.

The control of both temperature and humidity by artificial means seems to be the final solution of the problem in all cases where the establishment of mills in a relatively dry section is contemplated.

TABLE I.—*Monthly mean relative humidity at the stations named for the three years 1878, 1879, and 1880, except at Utica and the foreign stations.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass.	88.7	86.0	82.8	76.1	75.6	78.5	82.1	88.2	85.7	81.8	81.5	87.0	82.0
Woods Hole, Mass.	76.0	77.1	74.4	73.9	74.3	78.9	82.5	82.9	79.7	78.7	70.7	74.3	76.5
Newport, R. I.	87.0	85.0	83.0	81.0	89.0	87.0	87.0	86.0	89.0	80.0	82.0	85.0	84.0
New London, Conn.	71.5	72.8	72.5	71.6	71.5	75.2	75.7	78.7	78.3	78.4	72.9	74.2	74.0
.....	74.5	71.9	71.5	69.1	70.5	74.6	77.1	78.4	79.1	72.8	70.1	71.8	73.4
.....	76.0	75.0	73.0	72.0	80.0	81.0	79.0	82.0	82.0	77.0	77.0	76.0	77.0
Oswego, N. Y.	73.9	71.7	69.8	68.4	67.2	72.8	69.8	72.0	71.5	69.6	71.6	74.8	71.0
Utica, N. Y. ....	.....	.....	80.2	83.2	82.6	83.4	84.7	89.2	80.2	81.4	.....	.....	.....
Charlotte, N. C.	72.4	62.6	60.5	58.5	60.6	58.2	65.7	75.0	67.0	67.6	67.3	71.7	65.6
Wilmington, N. C.	70.2	66.3	66.2	64.9	70.6	70.5	73.6	78.6	75.0	74.3	72.2	71.4	71.2
Atlanta, Ga.	69.4	58.0	56.5	58.5	60.6	59.1	63.3	73.3	69.2	69.3	65.8	69.2	64.4
Augusta, Ga.	73.8	63.9	62.1	63.2	61.0	60.0	64.6	71.1	69.7	71.9	73.0	72.1	67.2
Mobile, Ala.	77.6	72.0	72.3	71.6	73.2	71.9	75.1	76.7	75.2	77.2	78.6	79.5	75.1
<i>English stations.</i>													
Lancaster, Lan.	90	90	80	71	74	78	78	84	82	84	87	90	82
Blackpool, Lan.	90	88	80	72	74	79	76	81	82	85	89	90	82
Bolton, Lan.	90	89	80	73	72	73	76	82	80	88	80	89	82
Macclesfield, Ches.	90	90	84	77	78	77	80	84	86	88	90	90	85
Northwich, Ches.	94	86	88	83	83	78	80	75	80	87	98	92	84

* From observations at 8 a. m. and 8 p. m., 24 years.

† From observations at 8 a. m. and 8 p. m., 7 years.

TABLE I.—*Monthly mean relative humidity at the stations named, etc.—Continued.*

States.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
<i>English stations—Cont'd.</i>													
Buxton, Derby. †.....	88	90	88	86	82	82	84	86	88	88	90	91	87
Cheadle, Staf. †.....	90	92	87	88	78	80	85	86	88	89	92	92	87
<i>Indian stations.</i>													
Bombay.....	70	69	73	75	74	82	87	87	86	80	71	70	77
Dacca.....	69	64	67	73	80	80	87	87	86	80	72	71	77
Madras.....	74	73	74	74	69	64	67	71	78	79	80	78	78

† Mean of 9 a. m. and 9 p. m. observations; mean of 9 a. m. obs. at other English stations.

TABLE II.—*Monthly mean relative humidity at the hours of 7 a. m., 2 and 9 p. m., local mean time, at the stations named below (1878-1880).*

Station.	January.			February.			March.			April.			May.			June.		
	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.
New Bedford, Mass..	94	69	90	94	76	89	88	73	89	81	62	85	79	62	86	80	68	87
Woods Hole, Mass..	79	72	76	79	74	78	78	68	77	77	67	78	75	67	81	79	72	86
Newport, R. I.....	76	65	73	78	66	75	77	65	74	78	62	75	77	61	77	80	66	80
New London, Conn..	79	67	77	77	63	75	76	63	75	74	59	73	73	62	76	78	66	80
Oswego, N. Y.	78	69	75	76	67	72	75	63	71	72	68	70	74	59	68	79	65	73
Utica, N. Y.*.....										80		80	84		82	85		80
Charlotte, N. C.....	83	62	72	76	50	61	73	47	62	71	44	61	73	46	64	67	45	63
Wilmington, N. C....	82	56	74	78	50	71	79	48	73	76	46	73	80	55	77	79	55	77
Atlanta, Ga.....	78	61	69	68	49	58	68	46	56	69	48	58	72	48	62	69	47	61
Augusta, Ga.....	83	61	77	78	49	65	78	44	65	76	46	67	74	43	67	73	43	64
Mobile, Ala.....	86	64	80	88	57	76	85	53	77	81	56	77	88	57	79	80	59	77

Stations.	July.			August.			September.			October.			November.			December.		
	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.
New Bedford, Mass..	86	70	90	87	71	91	91	75	91	89	69	86	82	68	85	92	78	91
Woods Hole, Mass..	88	78	87	86	75	88	84	72	83	80	67	75	75	65	72	78	71	75
Newport, R. I.....	90	65	82	88	69	84	85	68	82	81	64	76	79	66	73	78	68	77
New London, Conn..	79	69	84	82	69	84	84	70	84	80	61	77	76	62	72	75	66	74
Oswego, N. Y.	76	60	73	81	62	73	81	61	73	77	60	71	76	66	72	78	72	75
Utica, N. Y.*.....	86		85	85		84	91		88	81		80	84		79			
Charlotte, N. C.....	76	51	70	84	62	78	80	51	70	80	51	71	79	54	69	82	60	73
Wilmington, N. C....	82	59	79	86	66	84	86	59	80	86	56	81	83	56	78	82	58	75
Atlanta, Ga.....	73	52	65	84	60	76	81	57	70	79	58	71	76	57	65	79	51	69
Augusta, Ga.....	76	48	70	82	55	76	81	54	75	83	56	76	83	58	77	82	58	76
Mobile, Ala.....	82	63	81	89	56	85	86	58	82	87	62	82	86	64	84	86	70	83

TABLE III.—*Daily range of relative humidity as deduced from observations at 7 a. m., 2 and 9 p. m., local mean time, at places named.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass..	25	18	17	23	34	19	20	20	16	20	24	14	20
Woods Hole, Mass..	7	5	10	11	14	14	9	13	12	13	10	7	10
Newport, R. I.....	11	12	12	16	16	14	17	15	17	17	13	10	14
New London, Conn..	12	14	13	16	14	15	15	15	14	19	14	9	14
Oswego, N. Y.	9	8	12	10	15	14	16	18	20	17	10	6	18
Utica, N. Y.*.....													
Charlotte, N. C.....	21	26	26	27	26	22	25	22	20	20	25	22	25
Wilmington, N. C....	26	28	31	30	25	24	23	20	27	30	27	24	26
Atlanta, Ga.....	17	19	22	21	24	22	21	24	24	21	19	18	21
Augusta, Ga.....	22	29	34	30	31	30	28	27	27	27	25	24	28
Mobile, Ala.....	24	26	30	25	26	21	19	33	28	25	24	16	25

* Observations at 7 a. m. and 9 p. m. only.

† Can not be had; no observations at 2 p. m.

Three years observations, 1878-1880. It should be understood that the values given do not express the true daily range, but simply the closest approximation thereto that can be obtained from observations at the hours above named. Generally the 7 a. m. mean has been considered as the maximum and the 2 p. m. mean as the minimum; in the summer, however, the maximum at New England stations occurs at 9 p. m.

TABLE IV.—*Greatest change in the relative humidity of the air in eight consecutive hours during the years 1878, 1879, and 1880.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass.....	55	53	68	68	48	50	48	47	40	47	60	50	52
Woods Hole, Mass.....	50	39	44	43	47	40	36	45	34	43	41	41	42
Newport, R. I.....	55	44	48	47	45	43	47	43	40	49	43	34	45
New London, Conn.....	45	44	48	50	51	41	40	41	37	50	43	45	44
Oswego, N. Y.....	35	37	39	44	47	39	39	49	43	55	35	36	42
Utica, N. Y.*.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Charlotte, N. C.....	63	63	64	55	53	42	39	39	46	52	58	52	52
Wilmington, N. C.....	59	62	69	61	53	54	45	40	52	59	61	58	56
Atlanta, Ga.....	49	54	52	49	42	43	38	40	45	45	47	48	46
Augusta, Ga.....	57	60	65	64	62	52	50	46	53	57	52	60	56
Mobile, Ala.....	59	63	68	61	49	42	43	46	49	56	51	54	53

* Can not be obtained; no observation at 2 p. m.

The greatest change, whether a rise or fall in each month of the period named, was tabulated and the average change for the entire period was then obtained; thus, at Augusta, the greatest change in January of 1878 was 52 per cent; 1879, 59 per cent; 1880, 60 per cent; the average change for the month being 57 per cent.

TABLE V.—*Lowest relative humidity at the stations named during the years 1878, 1879, and 1880.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass.....	43	44	32	31	39	36	45	46	49	39	35	38	40
Woods Hole, Mass.....	36	40	34	37	31	39	46	48	43	33	38	45	39
Newport, R. I.....	36	38	31	31	23	29	33	44	40	31	34	47	34
New London, Conn.....	35	31	24	26	27	34	43	44	38	25	32	40	38
Oswego, N. Y.....	47	45	40	37	30	41	39	39	43	31	45	49	40
Utica, N. Y.*.....	.....	.....	.....	54	63	63	57	68	76	56	59†	.....	.....
Charlotte, N. C.....	25	21	12	15	22	26	33	43	28	23	21	27	26
Wilmington, N. C.....	24	19	17	17	24	31	37	43	35	22	24	26	27
Atlanta, Ga.....	27	22	17	21	25	25	32	36	33	25	25	28	27
Augusta, Ga.....	26	20	17	22	23	26	36	36	33	27	30	28	26
Mobile, Ala.....	24	23	16	19	23	34	40	45	36	23	26	23	26

* Observations at 7 a. m. and 9 p. m. only.

† For ten days.

The lowest relative humidity during each month of the period named was tabulated and the average of each month was then calculated. The figures, therefore, represent the average of the lowest degree of humidity each month.

TABLE VI.—*Lowest daily mean relative humidity for periods of twenty-four and forty-eight consecutive hours, respectively, during the three years 1878-1880.*

MEANS OF TWENTY-FOUR HOURS.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass.	65	62	54	53	52	54	64	69	63	58	64	66	60
Woods Hole, Mass.	58	56	51	51	50	52	60	63	54	45	50	53	53
Newport, R. I.	47	55	50	50	44	49	54	59	54	49	51	57	50
New London, Conn.	49	50	44	43	39	49	58	62	53	43	50	54	50
Oswego, N. Y.	59	53	57	53	46	58	57	53	56	54	53	60	55
Utica, N. Y.*	.....	.....	.....	60	70	68	66	75	82	68	66	.....	.....
Charlotte, N. C.	42	38	33	33	37	41	44	55	45	45	40	47	42
Wilmington, N. C.	41	39	34	36	46	50	53	59	52	44	44	44	45
Atlanta, Ga.	42	34	29	32	39	38	43	54	51	42	39	40	40
Augusta, Ga.	49	41	40	38	39	45	45	57	50	45	44	50	45
Mobile, Ala.	45	48	34	41	50	58	61	69	59	55	58	47	51

MEANS OF FORTY-EIGHT HOURS.

New Bedford, Mass.	74	67	63	55	56	59	66	71	70	68	67	72	65
Woods Hole, Mass.	62	60	60	54	53	55	65	67	56	56	52	58	56
Newport, R. I.	55	60	51	53	49	50	50	63	58	54	52	53	56
New London, Conn.	56	54	49	45	47	52	62	63	62	49	54	56	54
Oswego, N. Y.	68	62	59	55	54	59	59	61	58	56	57	63	59
Utica, N. Y.	.....	.....	.....	68	55	70	74	76	84	69	69	.....	.....
Charlotte, N. C.	50	42	37	36	42	42	44	56	48	50	45	49	45
Wilmington, N. C.	49	46	45	38	50	52	59	63	56	49	50	47	51
Atlanta, Ga.	46	37	32	34	40	41	45	56	52	44	41	46	43
Augusta, Ga.	53	46	43	42	46	47	46	59	54	50	51	58	49
Mobile, Ala.	50	51	42	43	55	54	62	70	61	58	56	53	55

*Observations at 7 a. m. and 9 p. m. only.

In obtaining the figures given in the above table the lowest daily mean relative humidity for each month of the period was tabulated and the mean of the three years calculated.

TABLE VII.—*Monthly mean temperature at the stations named (degrees F.).*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
New Bedford, Mass.	28	29	35	44	55	64	70	68	62	52	42	34	48	78
Woods Hole, Mass.	31	32	36	44	55	63	68	68	63	53	44	34	50	8
Newport, R. I.	30	32	36	44	54	64	70	70	64	55	42	34	50	8
New London, Conn.	29	30	35	46	56	65	71	69	64	53	43	34	50	18
Oswego, N. Y.	24	25	30	42	54	64	70	68	62	50	39	29	46	19
Utica, N. Y.	21	22	29	43	56	65	69	67	60	48	35	26	45	5
Charlotte, N. C.	42	46	50	60	69	76	79	76	71	61	51	44	60	13
Wilmington, N. C.	48	51	54	61	70	77	80	78	74	64	56	49	63	18
Atlanta, Ga.	43	48	52	62	69	76	78	76	72	62	52	45	61	18
Augusta, Ga.	48	52	56	64	72	79	82	80	75	65	55	49	65	18
Mobile, Ala.	51	56	60	67	74	81	83	81	78	68	57	53	67	18
<i>English stations.</i>														
Lancaster.	36	39	44	50	59	57	60	58	52	48	44	41	48	2
Blackpool.	37	40	43	48	52	59	61	60	56	49	45	40	50	3
Bolton.	35	38	40	46	51	57	59	58	54	47	42	38	47	4
Macclesfield.	34	37	39	46	50	57	58	57	53	45	41	37	46	4
Northwich.	36	39	41	48	54	61	62	61	56	48	43	39	49	4
Buxton, Derby.	33	36	37	41	47	53	56	50	52	44	40	36	44	6
Cheadle, Stafford.	34	36	40	42	48	54	57	57	53	45	41	37	45	6
<i>Indian stations.</i>														
Bombay.	73	75	79	83	85	83	81	80	80	81	79	76	80	44
Dacca.	66	70	74	78	83	83	83	83	83	80	74	78	78	21-23
Madras.	70	77	81	85	87	87	85	84	84	81	78	76	82	81

TABLE VIII.—*Monthly mean precipitation, in inches and hundredths.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
New Bedford, Mass.	3.90	3.62	4.17	3.96	3.95	3.15	3.36	4.28	3.48	3.68	4.31	4.11	46.31	75
Woods Hole, Mass.	3.70	3.70	4.90	4.30	3.00	2.70	3.30	4.10	3.40	4.10	4.80	3.30	44.90	13
Newport, R. I.	4.38	4.58	6.50	4.81	2.75	3.28	3.67	3.65	3.10	3.68	5.50	3.96	49.97	8
New London, Conn.	4.38	3.98	4.74	3.67	3.59	3.16	4.08	4.70	3.35	4.44	4.07	3.46	47.50	26
Oswego, N. Y.	3.10	2.80	2.80	2.10	2.50	3.30	3.40	2.50	2.80	3.40	3.30	3.40	35.00	23
Utica, N. Y.	3.34	3.10	3.07	2.88	3.63	4.28	4.62	3.71	3.54	3.44	3.85	3.68	48.09	38
Charlotte, N. C.	5.20	4.60	5.20	3.70	4.70	4.70	5.90	5.50	3.20	3.60	3.20	4.40	53.60	14
Wilmington, N. C.	3.90	3.30	4.20	3.10	4.20	5.90	7.30	7.80	6.70	4.10	3.60	3.20	56.30	21
Atlanta, Ga.	6.30	5.80	6.50	3.70	3.80	4.40	4.70	4.40	4.20	2.50	4.00	4.90	54.50	14
Augusta, Ga.	4.50	3.80	5.40	3.60	3.40	4.30	5.30	4.80	3.70	2.70	3.30	3.60	48.10	23
Mobile, Ala.	5.00	4.70	7.40	5.00	4.50	6.10	6.50	6.60	5.10	3.10	4.40	4.50	62.70	21
<i>English stations.</i>														
Lancaster.	2.20	4.58	2.23	1.06	2.60	2.47	3.20	4.58	2.72	4.38	2.92	3.80	36.88	2
Blackpool.	2.16	2.51	1.31	1.15	2.30	2.16	2.35	4.63	3.40	4.48	2.72	2.94	33.03	34
Bolton.	2.88	3.44	1.96	1.72	2.88	2.94	3.72	5.40	3.32	4.63	3.52	5.00	41.32	4
Macclesfield.	2.79	2.45	1.71	1.37	3.38	2.31	3.31	4.19	2.27	3.77	2.35	3.56	33.62	4
Northwich.	2.06	2.08	1.18	1.48	2.60	3.05	2.80	3.88	2.80	3.46	2.18	3.29	30.33	4
Buxton.	3.19	6.10	3.98	2.60	3.42	4.23	6.32	5.52	5.00	5.20	5.88	5.90	56.14	6
Cheadle.	2.22	3.48	2.38	2.02	2.37	3.24	4.28	4.48	3.42	2.61	3.27	3.32	37.99	6
<i>Indian stations.</i>														
Bombay.	0.12	0.01	0.00	0.04	0.53	30.45	24.12	12.88	9.65	2.02	0.49	0.05	70.30	30
Dacca.	0.36	0.99	2.55	5.74	9.04	13.29	13.07	13.35	9.72	5.17	0.72	0.19	73.23	40-42
Madras.	0.92	0.27	0.40	6.04	2.16	2.11	3.86	4.50	4.70	11.02	13.47	5.29	49.34	78

TABLE IX.—*Monthly mean cloudiness (scale of 0-10).*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
New Bedford, Mass.	5.0	5.0	6.0	5.2	4.8	4.9	5.1	5.0	4.8	4.7	5.2	5.4	5.1	5
Woods Hole, Mass.	5.9	5.8	5.3	5.1	5.4	5.1	4.4	5.1	5.1	5.6	5.5	5.7	5.4	8
Newport, R. I.	5.3	5.0	5.8	5.5	5.4	4.7	5.2	4.8	5.0	4.8	5.5	5.5	5.2	8
New London, Conn.	5.3	5.0	5.3	5.2	5.1	4.8	4.8	4.8	4.8	4.9	5.1	5.2	5.0	24
Oswego, N. Y.	8.2	7.6	6.9	5.6	5.4	5.0	4.7	4.8	5.1	6.5	8.0	8.5	6.4	24
Utica, N. Y.	7.8	7.8	7.6	6.3	5.5	4.7	5.2	5.1	4.9	6.4	7.3	4.0	6.4	34
Charlotte, N. C.	5.7	5.3	5.0	4.6	4.8	5.1	5.2	5.2	4.8	3.9	4.3	4.8	4.9	16
Wilmington, N. C.	5.3	5.4	4.8	4.4	4.6	5.0	5.2	5.3	4.8	4.0	4.5	4.8	4.8	24
Atlanta, Ga.	5.7	5.5	4.7	4.4	4.5	5.1	5.2	5.4	4.4	3.8	4.5	5.1	4.9	16
Augusta, Ga.	5.1	5.1	4.6	4.2	4.2	4.8	4.9	5.2	4.6	3.5	4.4	4.7	4.6	24
Mobile, Ala.	5.5	5.4	4.9	4.8	4.4	5.1	5.3	5.0	4.5	3.7	4.4	5.2	4.8	24
<i>English stations.</i>														
Lancaster.	7.4	4.8	2.6	5.5	6.3	6.4	7.3	6.9	7.0	.....	7.8	.....	.....	1
Blackpool.	6.3	7.7	4.9	5.8	5.1	4.9	5.2	6.2	6.4	6.5	7.9	7.6	6.4	* 3
Bolton.	7.7	8.3	6.0	6.0	7.0	6.9	7.6	7.8	6.7	7.3	8.5	8.1	7.4	4
Macclesfield.	7.8	7.2	6.0	5.4	6.8	6.3	7.8	7.5	6.4	6.9	8.1	7.4	7.0	4
Northwich.	6.4	6.0	4.0	4.1	6.0	5.4	5.7	6.6	5.9	5.7	6.8	6.5	5.8	24
Buxton.	7.4	8.1	7.4	7.0	6.5	7.3	7.3	6.8	6.9	7.1	7.2	7.6	7.2	6
Cheadle.	7.2	7.2	6.8	6.6	6.0	6.5	7.0	6.5	6.4	6.1	6.1	5.8	6.8	6
<i>Indian stations.</i>														
Bombay.	1.5	1.3	1.7	2.2	3.9	7.9	9.1	8.8	7.4	4.2	2.2	1.8	4.3	44
Dacca.	1.6	1.8	3.1	3.9	5.3	7.6	7.9	7.8	6.8	4.1	2.2	1.4	4.5	23
Madras.	3.9	2.6	2.4	2.9	3.9	6.4	7.1	6.5	6.1	6.1	6.1	5.3	4.9	21

* Record broken.

† Mean of 9 a. m. and 9 p. m. observations.



Plate I.—Curves typical of the relative humidity (1878-1880) at the places named.

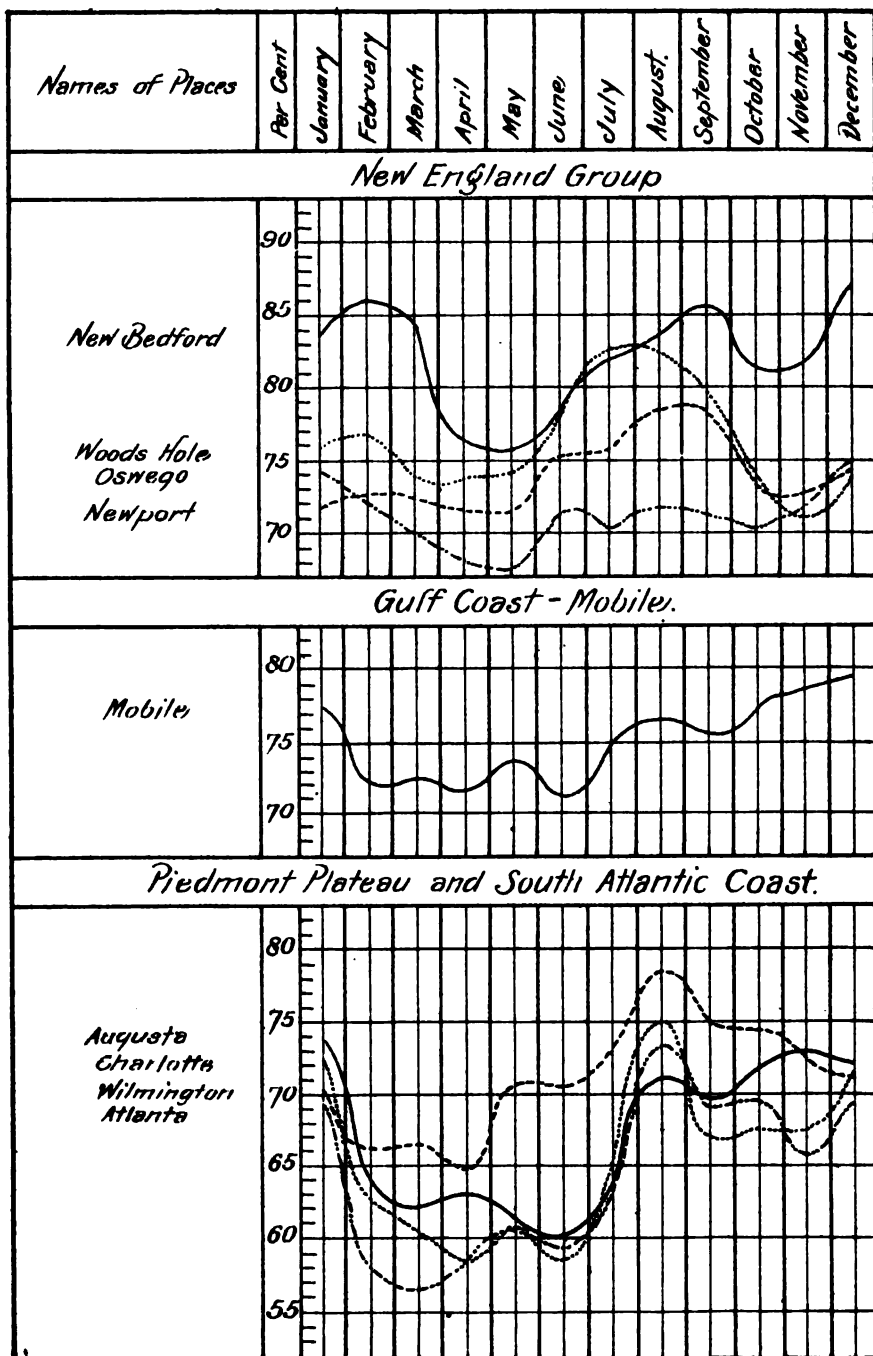
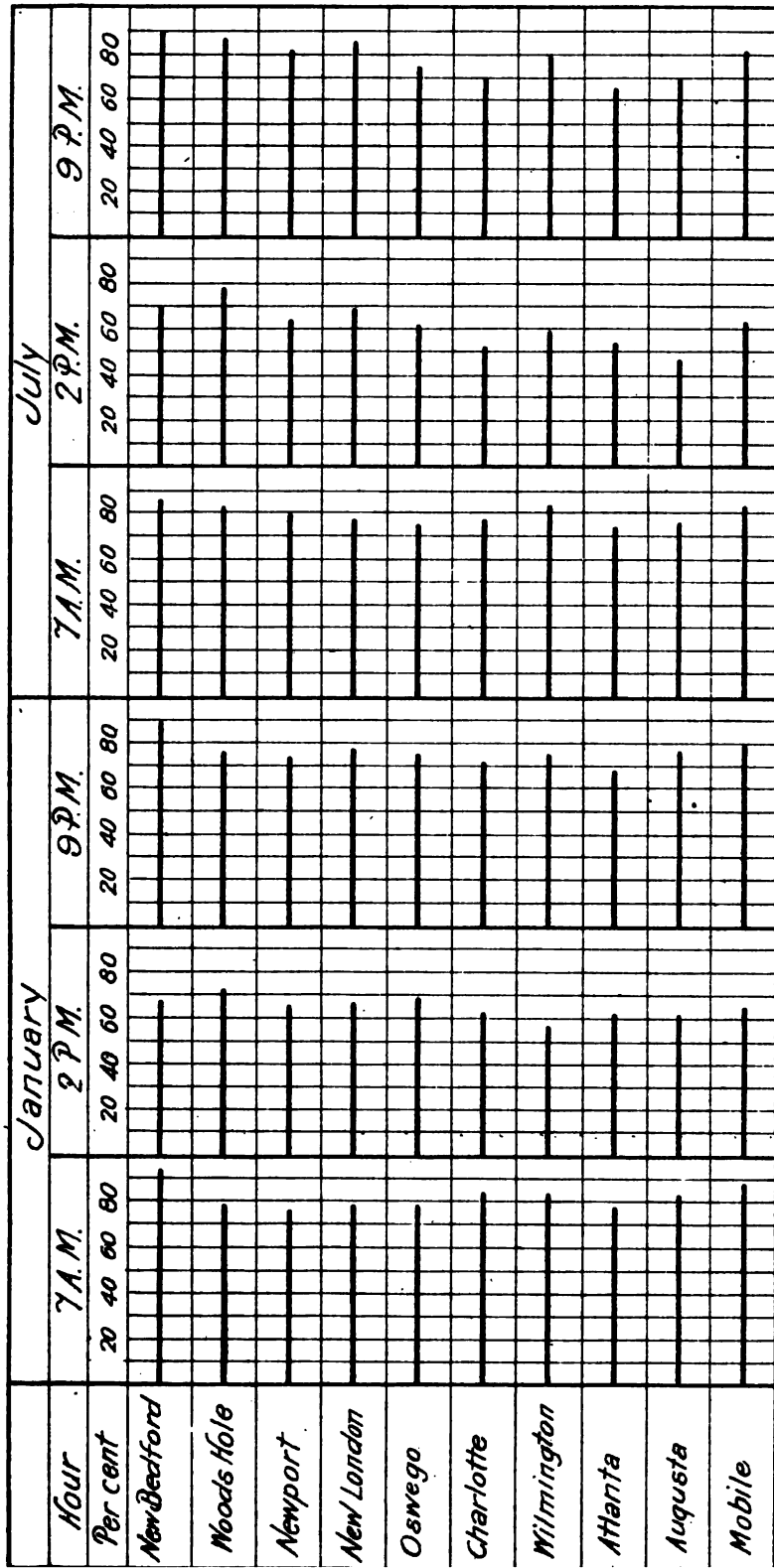




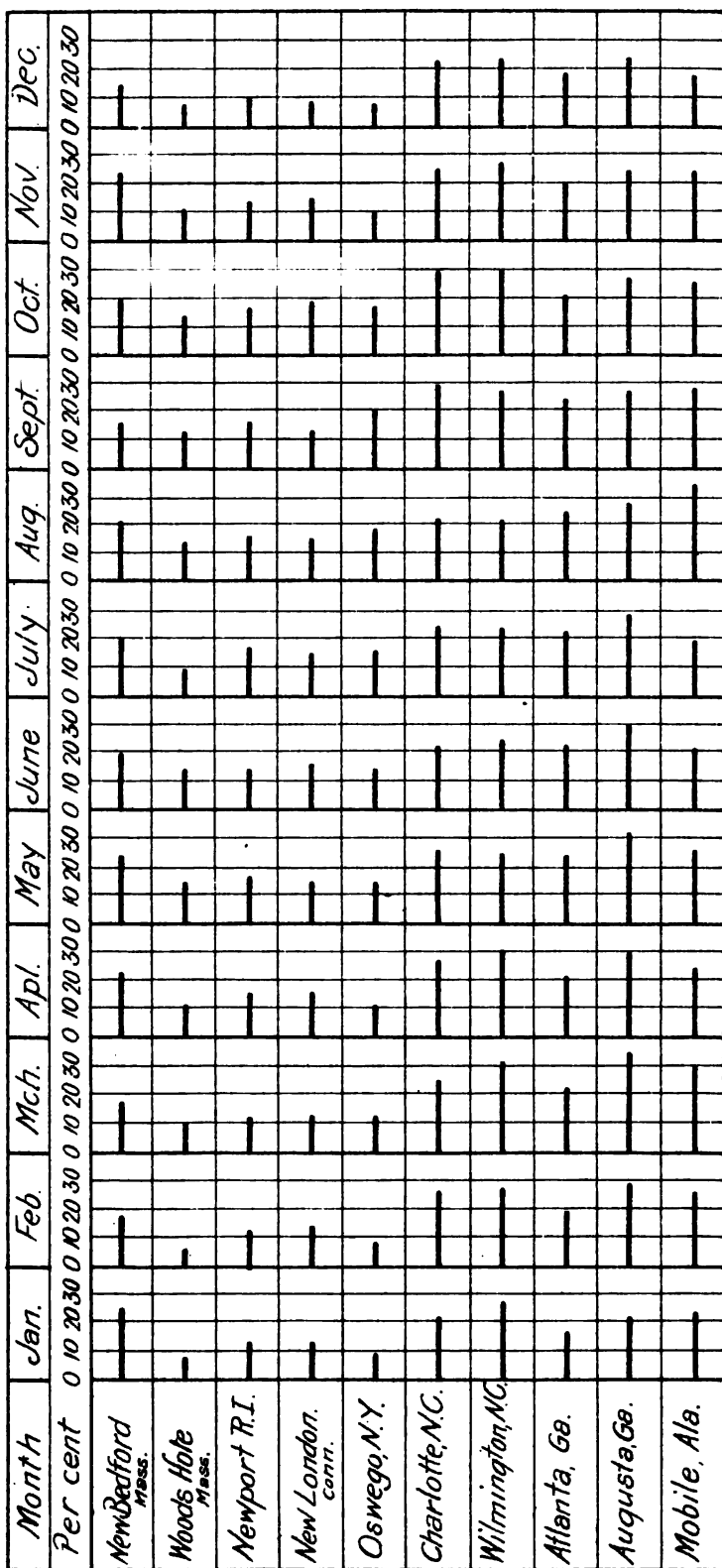
Plate II.—Relative humidity at 7 a. m., 2 and 9 p. m. for January and July.



The percentage of relative humidity at the hours named is proportional to the length of the heavy black horizontal line.



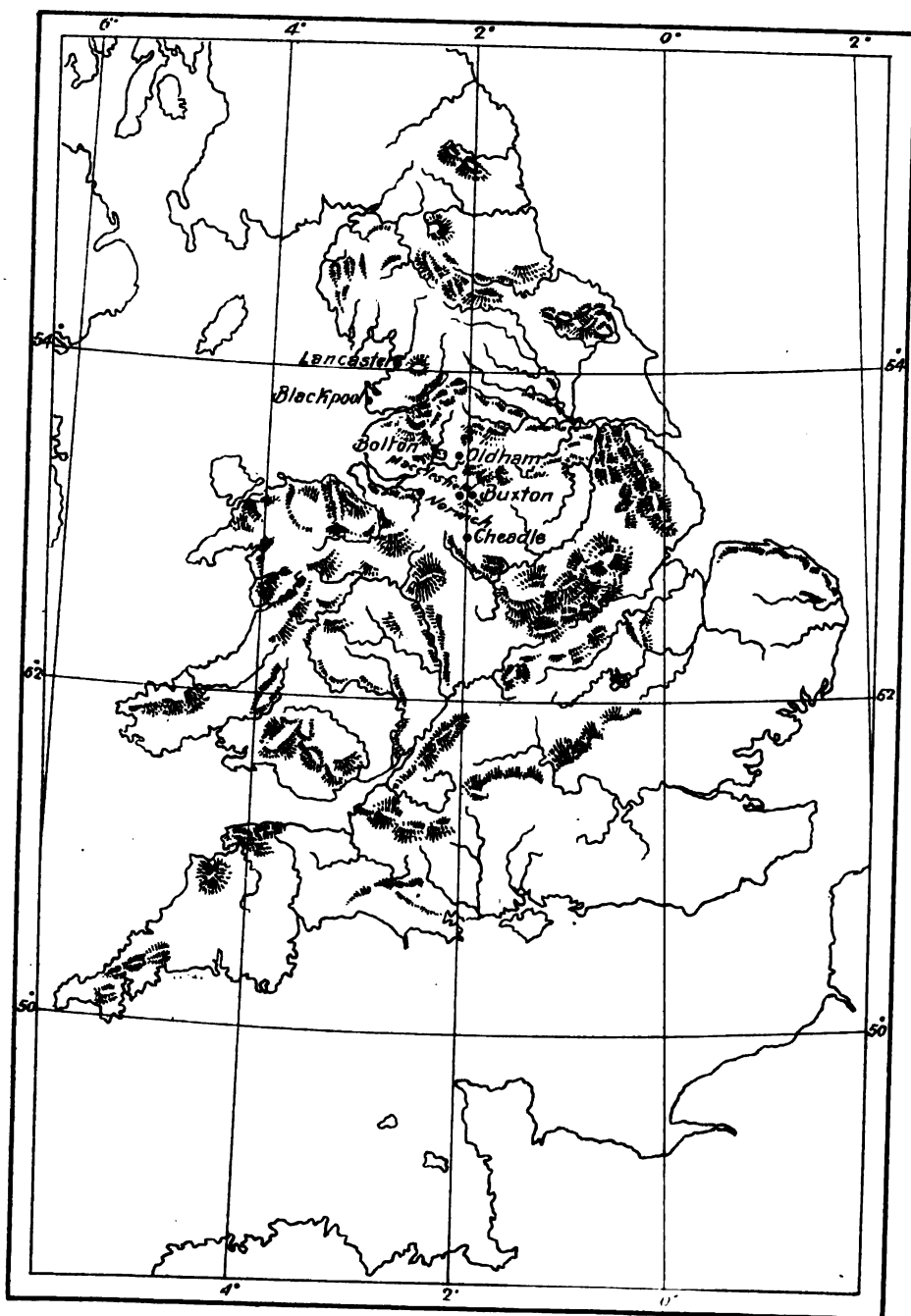
Plate III.—Diurnal variation of relative humidity.



The data from which this chart has been made are given in Table III. The heavy black horizontal lines indicate the daily range in humidity; in other words, the difference between the highest average humidity and the lowest average humidity. If the average at 7 a. m. is 80 per cent and at 2 p. m. 60 per cent, the average daily range would be 20 per cent. The ranges are drawn to scale, each vertical section representing 10 per cent.



Plate IV.—Sketch map of English stations.



U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

STORMS, STORM TRACKS,

AND

WEATHER FORECASTING.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau,

BY

FRANK H. BIGELOW,
Professor of Meteorology.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1897.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF CHIEF OF WEATHER BUREAU,
Washington, D. C. July 11, 1896.

SIR: I have the honor to submit herewith a bulletin by Prof. Frank H. Bigelow, of the Weather Bureau, entitled Storms, Storm Tracks, and Weather Forecasting.

Its purpose is to present the latest phases of the science of meteorology as regards practical forecasting of weather conditions. It is believed that the bulletin will be found of particular value to those engaged in teaching meteorology, and also to students of the subject. Furthermore, it is intended to be of assistance to the observers and other officials of the Weather Bureau, and, in so far as it treats of weather forecasting by months and generalizations on the same, it is recommended for their careful study, as the most lucid exposition so far presented for their information.

In order to foster an intelligent interest in some of the laws probably influencing the weather conditions, Professor Bigelow has added a brief statement of the relations that appear to exist between the solar magnetic energy and the pressures and temperatures of the Northwest. It is not intended by him to put this forth as a finished working system for forecasting, but only as an illustration of the knowledge that is being developed in this interesting and important field of research.

I respectfully recommend that it be published as a bulletin of the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,
Chief of Bureau.

Hon. J. STERLING MORTON,
Secretary of Agriculture.

CONTENTS.

	Page.
Introduction:	
Cooperation of the press with the Weather Bureau—How to construct a daily weather map	5
Weather forecasting, by months:	
August—	
Mean storm tracks—Districts of local origin—August storms and tracks	10
September—	
September storms—Mechanism of a hurricane	16
October—	
The three primary divisions of the meteorological year—Storm tracks and weather conditions for October—Frost formation in the autumn.	21
November—	
Storm tracks—Why the weather becomes drier in the autumn—Isobars and wind lines in a typical central storm	26
December—	
Characteristics of the winter circulation—December storm tracks and the principal types of storms	32
January—	
Importance of the Northwestern districts—Storm tracks—Texas storms—Cold waves	37
February—	
Irregular rate of eastward drift of storms	43
March—	
The breaking up of the winter conditions and the widely scattered systems of storm tracts	45
April—	
Formation of the Rocky Mountain low—Causes of rainfall—Storm tracks—Frosts in spring	50
May—	
Storm tracks	55
June—	
Local weather conditions	57
July—	
Storm tracks and weather conditions—Formation and characteristics of tornadoes	59
Weather conditions at Washington, D. C., for the twenty-six years 1871-1896..	62
Circulation of the atmosphere in the upper levels—The international cloud observations	63
Description of the solar magnetic period of 26.68 days and its relation to the formation of storms in the North west—Definitions of the terrestrial magnetic elements—Solar magnetism and its connection with the weather	67
General remarks on forecasting	77
Practical weather forecasting	77
Long-range forecasting	81
Summary	86

ILLUSTRATIONS.

	Page.
Chart 1. Map of Thursday, August 1, 1895, 8 a. m.	7
2. Mean tracks of storms in the United States.....	11
3. Districts adopted for the study of the origin of storms	13
4. Storm tracks for August	15
5. Storm tracks for September	17
6. Storm tracks for October	23
7. Storm tracks for November.....	27
8. Isobars and wind lines.....	29
9. Storm tracks for December.....	34
10. Storm tracks for January	40
11. Storm tracks for February	44
12. Storm tracks for March	46
13. Storm tracks for April	53
14. Storm tracks for May	56
15. Storm tracks for June.....	58
16. Storm tracks for July	60
17. Coordinates of normal and deflecting magnetic forces.....	72
18. General relations of the magnetic fields of the sun and the earth ..	74
19. Relative number of the direct type occurring annually, showing the semiannual periodic inversion. From the magnetic data 1841- 1894	84
20. Semiannual period in the inversion of the direct type of the solar magnetic curve	85

STORMS, STORM TRACKS, AND WEATHER FORECASTING.

INTRODUCTION.

COOPERATION OF THE PRESS WITH THE WEATHER BUREAU—HOW TO CONSTRUCT A DAILY WEATHER MAP.

The policy of the Department of Agriculture is to place before the people of the United States as much practical scientific information as possible. This knowledge really belongs to the people, inasmuch as they sustain the necessary expense of collecting the data upon which investigations are made. When valuable results are acquired, the wide publication of the same, in as simple language as is consistent with the subject, is a primary duty.

The Assistant Secretary of the Department of Agriculture, Dr. Charles W. Dabney, jr., is especially in charge of this popular distribution of scientific knowledge, and has enjoined upon the bureaus and divisions of the Department the duty of cooperating in this direction.

The Weather Bureau, which has charge of the collection and dissemination of all proper information regarding the ever-changing weather conditions, so directly affecting the wealth and health of the people, has, in accordance with the policy of the Department, had this bulletin prepared, which, it is thought, contains valuable information on the subject.

The very important cooperation that the press is giving to the distribution of weather information in this and other communities is most gratifying. While it is possible for the Government to publish a comparatively small number of the daily weather maps of a large size, and to distribute these by messenger or by mail, it is nevertheless plain that main reliance must be placed upon the daily press for this purpose. Since a practical way has been found to make clear small reproductions of the large map, the necessity for the Government map is somewhat modified, because the general points of the current weather conditions are displayed sufficiently well for all common purposes on the reduced scale. Moreover, the advantage is all with the papers in reaching larger numbers of people.

Reports are being constantly received of an increasing interest in the daily weather map on the part of many persons who have been attracted by the press reproductions, and very often these are accompanied by the expression of the wish that they could understand the

meaning of the lines a little better. The proportion of readers who perceive the significance of the lines showing temperature and pressure of the air, as they change from map to map in their location, is already great, and it is thought that with a little care and effort nearly every one who can read may also comprehend the daily map, at least approximately.

It is like learning a new language, and at first costs some labor, but when once the symbols are understood there is a pleasure in reading the same that compensates for the intellectual work expended. "How to construct a daily weather map" is therefore addressed to those who have not quite mastered the symbols and the lines on the map, and to those who have not yet attempted to look into it at all. If some one in each family will take the trouble to follow the directions that are given herewith, it will not be long before every member can take an interest in this branch of the Government service.

It is well known that the forecasters of the Weather Bureau often make mistakes in their efforts to interpret the probable changes in these lines for a day or two ahead, and that in consequence they are subject to criticism by the public for their failures. On comparing these criticisms from different portions of the country, it is seen that the people who best understand the difficulties of the art of forecasting are most just in their criticisms, and that generally the press has been fair in its statements. This is no doubt in a measure due to the advantage that the reporters of the press have in their frequent visits to the central and local offices of the Weather Bureau, by which they are more in touch with the details of the work itself. In the same way, the more familiar the people of any locality are with the way of making the forecasts, the more considerate they are of failures to reach perfection. It is therefore desired that every one should know as much as possible on this subject, to the end that criticisms arising from impatience and partial knowledge may be corrected. Meteorology as a science is in some respects still in its elementary stages of growth, and there is much to be discovered about the laws controlling the atmosphere. The wonder is that so imperfect a science can have already contributed so much to the benefit and protection of the people. It is to be hoped that maps of artistic merit may become regular features of the journalism of the large cities of the United States.

This bulletin gives for each month of the year the meteorological normal conditions and the prevailing features of the storm tracks characteristic of the month, with such remarks as will direct attention to the main types of weather to be expected during the month; also general remarks on forecasting, embracing long-range forecasting.

The first thing to understand is how to draw in the lines that appear on the map. About 142 observations, 8 a. m. and 8 p. m. daily, are received from different points of the country, taken all at the same moment of time for a given map. For the 8 a. m. map they are tele-

graphed in and received at Washington between 8.30 and 9 o'clock. These are entered on charts, the forecaster reads the meaning, and the

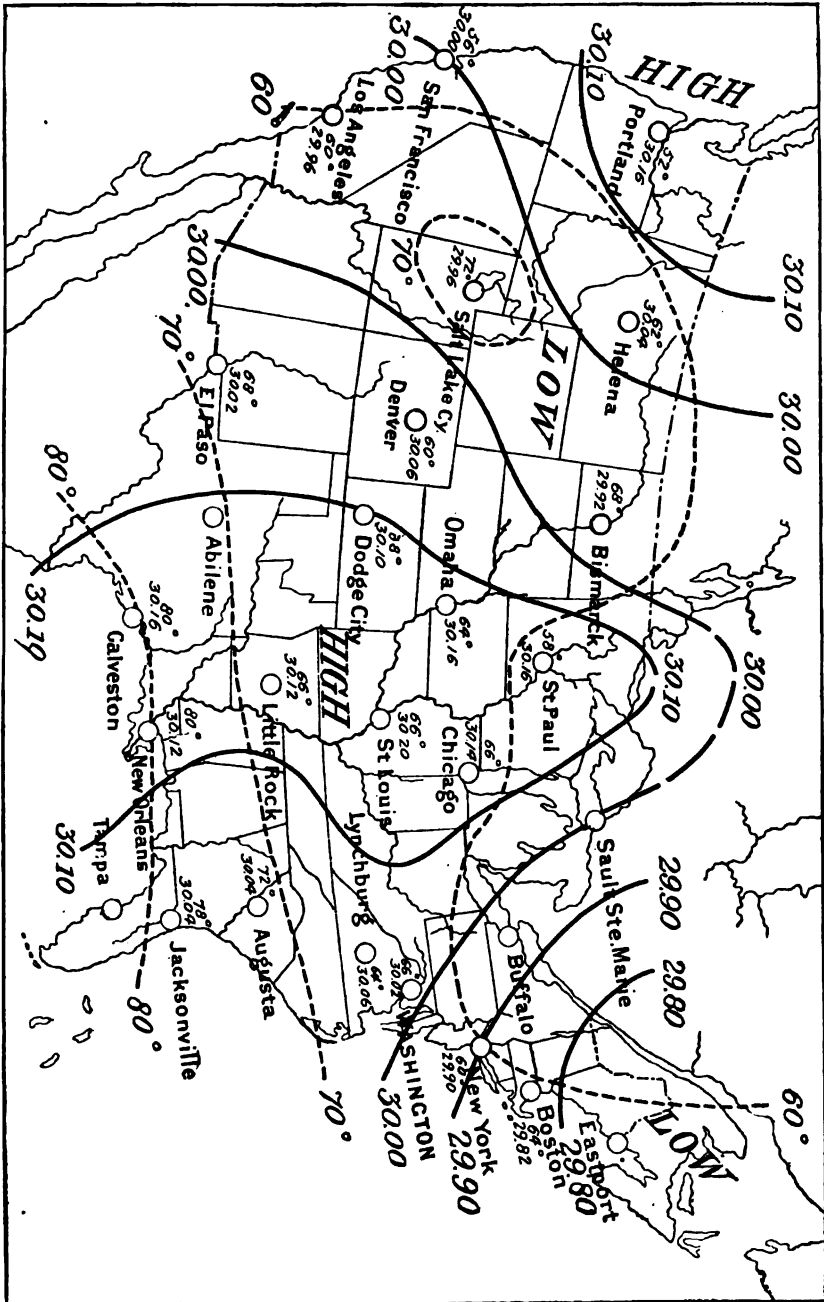


Chart 1.—Map of Thursday, August 1, 1895, 8 a. m.

forecasts are out by 10 or 10.30 o'clock. On Chart 1 only 22 of these places are laid down, so as to avoid crowding on the reduced scale.

For illustrating the mode of drawing the lines the Washington map of Thursday, August 1, 1895, 8 a. m., is selected. Against each of the 22 cities are written two sets of figures, the upper giving the temperature and the lower the pressure of the air at 8 o'clock in the morning of August 1. Thus the temperature at Boston is 64° and the pressure 29.82 inches; at New York, 60° and 29.90 inches. Toward the west the time of the observation is earlier in the morning; that is, in the Mississippi Valley the observer reads his instrument at 7 o'clock, local time; on the Rocky Mountain slope, at 6 o'clock, and on the Pacific Coast, at 5 o'clock, so that all the observers may read at the same moment. Cooperation is, therefore, the peculiar feature of the operations of the service. On looking over the map the simplest question to ask is, Where do the same temperatures prevail, and where are the pressures just alike? It is evidently helpful to the eye to draw a line through the places where the same conditions exist, and it is most convenient to select the even 10° differences, and the even 10-inch differences for such connecting lines. That is, dotted lines are drawn through all places having the temperatures 60° , 70° , 80° , and solid lines through the places having the pressures 29.90 inches, 30 inches, 30.10 inches, barometric pressure. Now, in order to do this it becomes necessary to interpolate the spaces. It is seen that the temperature at Galveston and New Orleans is 80° , and a line can be drawn through these, but for Jacksonville the temperature is only 78° , and the 80° line must run a little south of it to allow for the drop from 80° to 78° in going northward. For the 70° line the process is as follows: At El Paso the temperature is 68° , and evidently the 70° line must lie between El Paso and the 80° line at intervals of 2° on the El Paso side and 10° on the Galveston side; near Little Rock, 4° on one side and 10° on the south side; near Lynchburg, 6° on the north side and 10° on the south side. The intervals 2 to 10, 4 to 10, 6 to 10 are the interpolations referred to, and by a little practice can be very rapidly performed. In the case of the 60° line the process is the same, and it runs through Los Angeles, between Portland and Helena, 8 to 2; between Bismarck and St. Paul, 8 to 2; between St. Paul and Chicago, 2 to 6; north of Washington, through New York, and west of Boston. These dotted lines of equal temperature are called *isotherms*.

In a similar manner interpolate for the pressure lines. Thus the 30.10-inch line runs between El Paso and Galveston, 8 to 6; through Dodge City, west of Omaha, between Bismarck and St. Paul, 18 to 6; returns southward between Chicago and Washington, 4 to 8; between St. Louis and Lynchburg, 10 to 6; between Little Rock and Augusta, 2 to 6, and between New Orleans and Jacksonville, 2 to 6. The 30-inch line starts between Los Angeles and El Paso, 4 to 2, and passes between Salt Lake City and Denver, 4 to 6, just east of Bismarck; follows the general curve of the 30.10-inch line and passes between Washington and New York, 2 to 10. Another 30-inch line passes through San Francisco, between Helena and Bismarck, 4 to 8. Another 30.10-inch line passes between Portland and Helena, 6 to 6. A 29.90-inch line passes

through New York City and a 29.80-inch line just north of Boston. These lines should always be drawn so as to harmonize with each other, making a system of curves that grade into each other by easy changes. Such lines of equal pressure are called *isobars*.

These details are given in the hope that readers will take the trouble to construct, from the map given for the purpose, a little map for themselves by way of practice. Take some semitransparent paper and trace the base lines, the boundaries, and the rivers, and locate the 22 cities. Copy against each city the figures for the temperature and the pressure, and then interpolate the dotted lines for temperature and the solid lines for pressure. The figures in Chart 1 are taken from the first and third columns of the table as printed on the right-hand side of each large weather map issued by the Weather Bureau. If anyone will copy the base map and these figures for a few days in succession, and then plot in the isotherms and the isobars, and will thus watch the variable positions on the maps from day to day of the lines of the same name, a clear idea of the fundamental features of the weather map will soon be secured.

In addition to these lines, symbols for wind and weather are used: For wind, an arrow on the station circle pointing the way the wind blows, and for weather—clear, a fine-line circle; cloudy, a full-shaded circle; partly cloudy, a half-shaded circle; raining, the letter R, and snowing, the letter S, at the station. A general rain area is shaded on the map.

Near the center of an area of high pressure above 30 inches is placed the word "high," and near the center of a region of pressure less than 30 inches is placed the word "low." A low-pressure system is called a storm or a cyclone, and the winds blow around the center in the opposite direction to the hands of a watch as one looks on the watch lying upon the map with the face up. The high-pressure system is called an anticyclone, and the winds blow around its center in the general direction of the hands of a watch, though in a less distinct manner than in the cyclone. The winds always blow down the gradient from the high to the low, from the anticyclone to the cyclone.

These are the chief features on any weather map, so far as its construction goes. Those who wish to learn to understand the meaning of the same in regard to the resulting weather conditions should construct them for themselves, until familiar with the details. Then they should carefully compare the maps from day to day and observe the differences that have taken place in twenty-four hours, in forty-eight hours, and in seventy-two hours. The easiest way to do this is to cut out the press map every day and lay the successive maps in a column, above one another, so that the eye may take in at a glance the changes that have been going on. A short practice in this manner will enable one to follow the storms as they pass from west to east, and will also soon give the ability to judge from the maps what the weather conditions are likely to be during the following twenty-four hours.

WEATHER FORECASTING, BY MONTHS.

AUGUST.

MEAN STORM TRACKS—DISTRICTS OF LOCAL ORIGIN—AUGUST STORMS AND TRACKS.

The first impression of any student on approaching the practical use of the weather maps, as they present their seemingly endless forms and combinations of the temperature and pressure lines, is one of confusion. This feeling is also sure to be attended by one of discouragement, and probably the impulse to abandon the task of seeking an underlying plan is more powerful to many persons than the incentive, which depends upon curiosity, to know what it all really means.

The storms of the United States follow, however, year after year a series of tracks, not capricious, but related to each other by very well-defined laws.

The positions of these tracks have been determined carefully for the United States by studies made in the forecast division of the Bureau, on the long series of maps that have been made during the past twenty years. The line that the central point of a high area or that the center of a storm makes in passing over the country from west to east is laid down on individual charts, these are collected on a group chart, and from this the average line pursued can be readily described. Chart 2 shows the general result of a study of tracks of storms in the United States. It indicates that, in general, there are two sets of lines running west and east, one set over the northwestern boundary, the Lake region, and the St. Lawrence Valley; the other set over the middle Rocky Mountain districts and the Gulf States. Each of these is double, with one for the highs and one for the lows. Furthermore, there are lines crossing from the main tracks to join them together, showing how storms pass from one to the other. On the chart the heavy lines all belong to the tracks of the highs and the lighter lines to the lows. Let us trace them somewhat in detail. A high reaching the California coast may cross the mountains near Salt Lake and then pass directly over the belt of the Gulf States to the Florida coast; or it may move farther northward, cross the Rocky Mountains in the State of Washington, up the Columbia River Valley, then turn east, and finally reach the Gulf of St. Lawrence. We may speak of the lower track as the *southern circuit* and the upper as the *northern circuit*. These are located where they are by the laws of general circulation of the atmosphere and configuration of the North American continent. This movement of the highs from the middle Pacific coast to Florida or to the Gulf of St. Lawrence is confined to the summer half of the year—April to September, inclusive.

In the winter months, on the other hand, the source of the highs is different, though they reach the same terminals. In the months October to March, inclusive, many highs enter the United States near the one hundred and fifteenth meridian and flow south along the Rocky

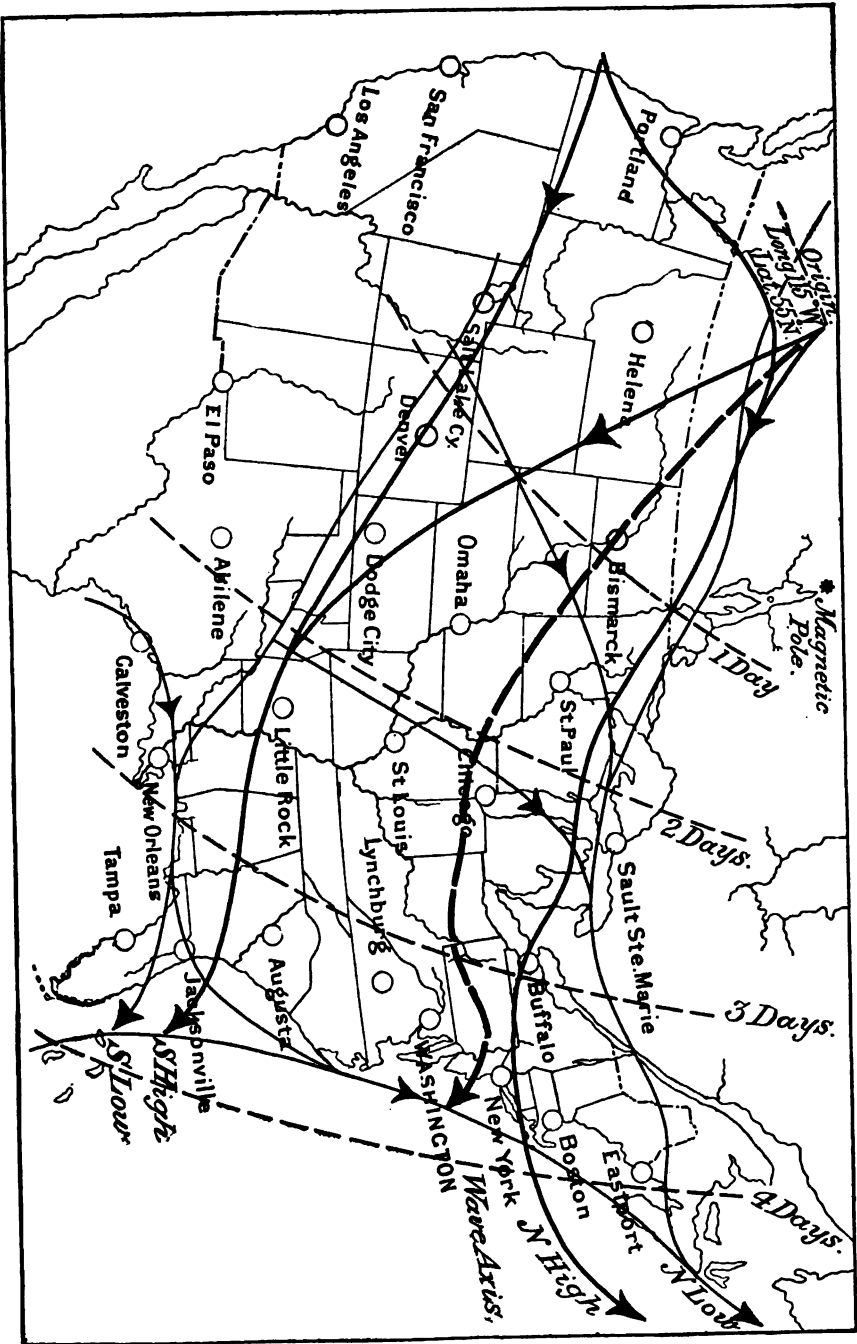


Chart 2.—Mean tracks of storms in the United States.

Mountain slope into the southern circuit, and thus reach the South Carolina coast; or else they turn more abruptly eastward and move in the northern circuit over the Lakes to Newfoundland. The chief difficulty in the art of forecasting is to decide from the current lines on a map which of these paths will be pursued, and then the probable rate at which the movement will take place.

Chart 3 shows the nine districts that have been adopted in the study of the local origin of storms, the total number of storms that formed in each district for the ten years 1884-1893, and the average track that the storms passed over in moving from their place of origin to the Gulf of St. Lawrence.

The storms or centers of low pressure are strictly dependent for their life upon the highs, being, in a word, only the natural mode of the disintegration of the highs, and the raising of the air by force against gravitation, from lower to higher levels in the atmosphere. The highs have two main places of entry into the United States, but the lows have at least nine places of generation, or entrance upon our territory. First, a majority of our storms originate in the region north of Montana, in Alberta, and move eastward, while some make a loop southward over the mountain slope before regaining the northern circuit; second, a number appear on the North Pacific coast and eventually disappear over the Gulf of St. Lawrence, if they live so long; third, others form on the northern Rocky Mountain plateau and follow the same track as the North Pacific coast storms; fourth, a large number from near Colorado are apparently produced by the very high mountainous elevations of that district, and usually join the northern circuit near the Great Lakes; fifth, the lower lands of Texas, catching the Gulf winds and moisture, generate a few storms each year, and these move northeastward over the central valleys to the lower lake region, whence they proceed down the St. Lawrence Valley, but a few storms come in from the extreme west of the Gulf of Mexico, enter the southern circuit near the mouth of the Mississippi River, whence they usually advance along the Gulf Coast and then near the Atlantic Coast to join the great track to the north and east of New England; sixth, the West Indian storms, or hurricanes, come in from the southeast near the twenty-fifth parallel, recurve northward and hug the Atlantic coast line to Nova Scotia, some other storms, however, appear in the east Gulf States; seventh, a few are first seen on the South Pacific coast; eighth, others begin on the South Atlantic coast and are strictly coast storms; ninth, some storm formations occur in the central valleys. These are the main tracks, though, of course, many instances occur in which it is hard to satisfactorily classify them. It is seen that wherever the storms may arise, whether in Alberta, on the Pacific Coast, in Colorado, Texas, Mexico, or in the West Indian region, they all try, sooner or later, to leave the United States in the neighborhood of New England. This is evidently a sufficient explanation of the very variable and the extremely harsh

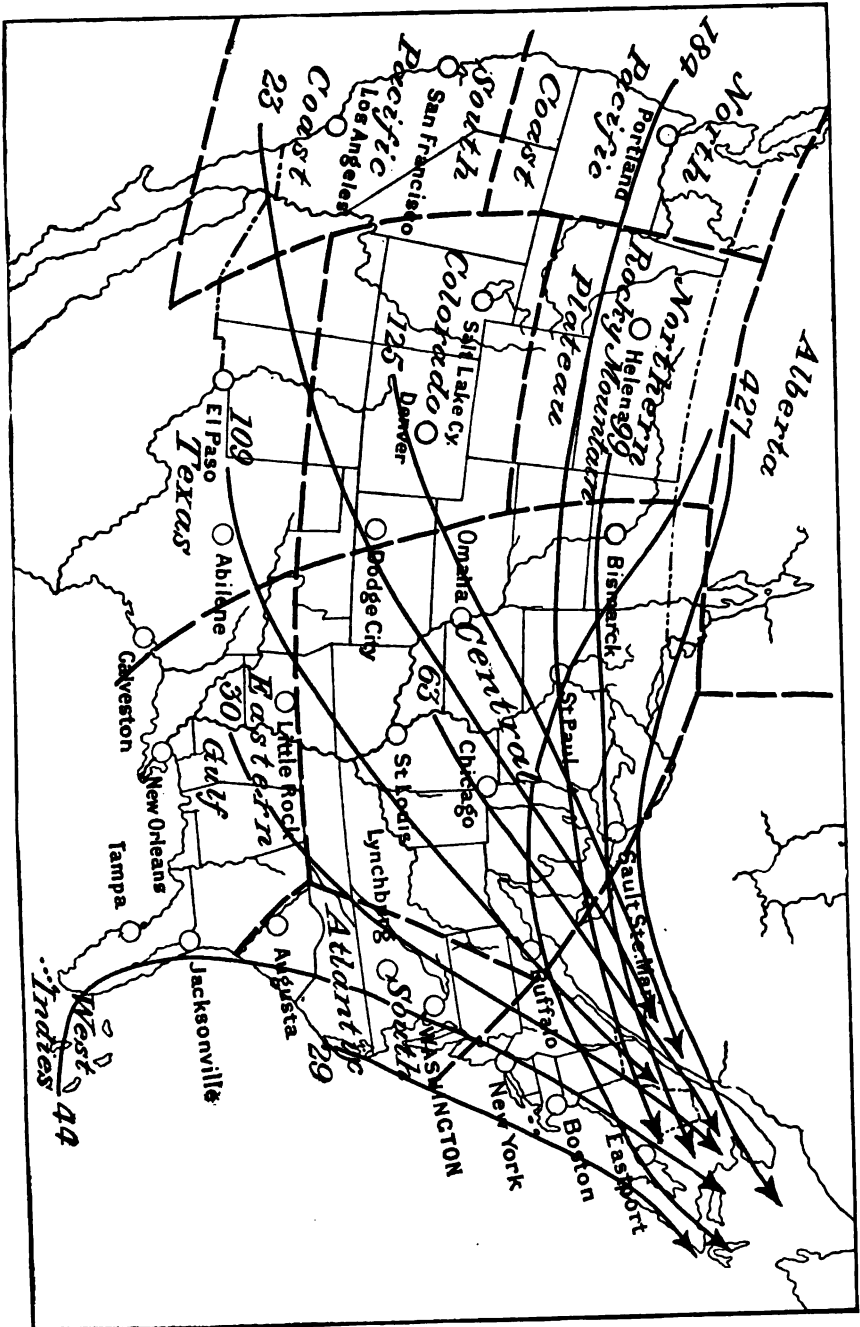


Chart 3.—Districts adopted for the study of the origin of storms.

weather that is so peculiarly the lot of that region. If all roads lead to Rome, all storms and weather tracks lead to New England.

There are seen on Chart 2 two other systems of lines, (1) those marked one day, two days, three days, four days, and (2) that marked wave axis. The former shows the average position of the storms that come in from the northwest on successive days, that is, after one day it will be found on the Rocky Mountain slope, in two days near the lower Missouri and Mississippi valleys, in three days near the Appalachians, in four days decidedly over the ocean. The latter shows the middle frontage of the cold waves as they come down from the northwest in the winter season.

The storms of August belong almost entirely to the Alberta, the Colorado, and the West Indian types. In ten years it was noted that 83 storms came into the field of the weather map in the month of August. Of these, 45 originated to the northward of Montana, or in the northwestern districts, and all of them moved eastward over the Lakes and the valley of the St. Lawrence to the ocean, a few of them dissipating on the way. More than half of the August storms begin and move along the northern circuit, like beads on a string, with great regularity. The breadth of the track covered by them is about 400 miles. This accounts for the fact that in the Northern States the alternation of warm and cool days takes place with wave-like regularity, while in the Southern States the temperature is almost uniform, though warm, week after week.

The next important place for August storms to come from is the State of Colorado, and it is found that in the same ten years 12 storms originated near there, moved northeast over the Lakes, joined the main branch in that district, and pursued their course eastward to the ocean. These Colorado storms in summer are apt to be accompanied by the warm wave that seems to set in at the eastern base of the Rocky Mountains and to gradually spread over the entire country to the Atlantic.

The third important system of storms are the hurricanes that arise in the trades of the Tropics, move westward to the Gulf of Mexico, curve up northward and enter the United States in the Lower Mississippi Valley, or skirt the coast districts, or else keep off the shore in the neighborhood of the Gulf Stream. These storms move in parabolic-shaped tracks, and spread over a very wide belt in the latitude of the Gulf States, east and west, whence comes the chief uncertainty in forecasting their approach to the coast of the United States. Eventually they advance to the same point of departure, the Gulf of St. Lawrence and Newfoundland.

Only 14 other storms were observed in the ten years 1884 to 1893, inclusive, scattered over the country in a very desultory way. August storms travel at the rate of 16 to 26 miles per hour, or about 500 miles a day. The question of the rainfall attending these storms is too large to consider, but it can be broadly stated that precipitation takes

place to the east and south of the storm center. Much of the rain in August is sporadic, in the form of thunderstorms, and these seem quite as ready to occur in connection with the high areas as in the low. This makes it much more difficult to satisfactorily forecast the time and place of these small local storms.

The months of August, September, and October make up the hurricane season, because tropical storms are most frequent during these months. Of the 12 hurricanes referred to, 5 first appeared near the Windward Islands. Two of these recurved east of the Florida peninsula, 2 disappeared over the Gulf of Mexico; 1 crossed Cuba and the Gulf of Mexico in 1886, and upon reaching the Texas coast, on the 20th, destroyed Indianola; passing thence northwest this storm dissipated over the southern Rocky Mountain region during the 21st and 23d. Two cyclones apparently originated near the Bahamas, one of which recurved northeastward off the North Carolina coast, and the other reached the Louisiana coast and moved thence northeastward over the lower Mississippi and Ohio valleys, New England, and Nova Scotia. The remaining 5 cyclones appeared north of the West Indies and east of the seventieth meridian. One of these reached the North Carolina coast August 23, 1893, skirted the middle Atlantic coast, and crossed New England. Another was the destructive storm which devastated the south Atlantic coast on the 27th and 28th of August, 1893. The mechanism of these destructive storms, which is very interesting, is given under September.

The hot waves of August come from two sources. They originate in a mass of heated air on the Rocky Mountain plains and gradually move eastward from thence. On the other hand, a high area settling over the south Atlantic and Gulf States has the effect of charging the stagnant air with heat, as if the eastward circulation in the upper air was suspended for quite long intervals of time.

SEPTEMBER.

SEPTEMBER STORMS—MECHANISM OF A HURRICANE.

One of the chief interests, aside from the value they have in respect to forecasting, in the study of charts of storm tracks consists in comparing them month with month, in order to observe the changes that take place with the progress of the seasons. It is shown on Chart 4 under August that the summer storms, in the majority of cases, originate in three places, in Alberta, Colorado, and the West Indies. On the other hand, in September Chart 5 indicates that they arise in at least six places. We have one set of storms generating in Alberta, of which 39 were observed in ten years; there were 13 noted that entered the North Pacific coast of the United States; next, 5 were observed to commence their activity on the northern plateau of the Rocky Mountains; also, 7 developed over the isolated plateau of Colorado; 8 appeared on the west coast of the Gulf of Mexico or in Texas; finally, 7 tropical hurricanes came in from the West Indies.

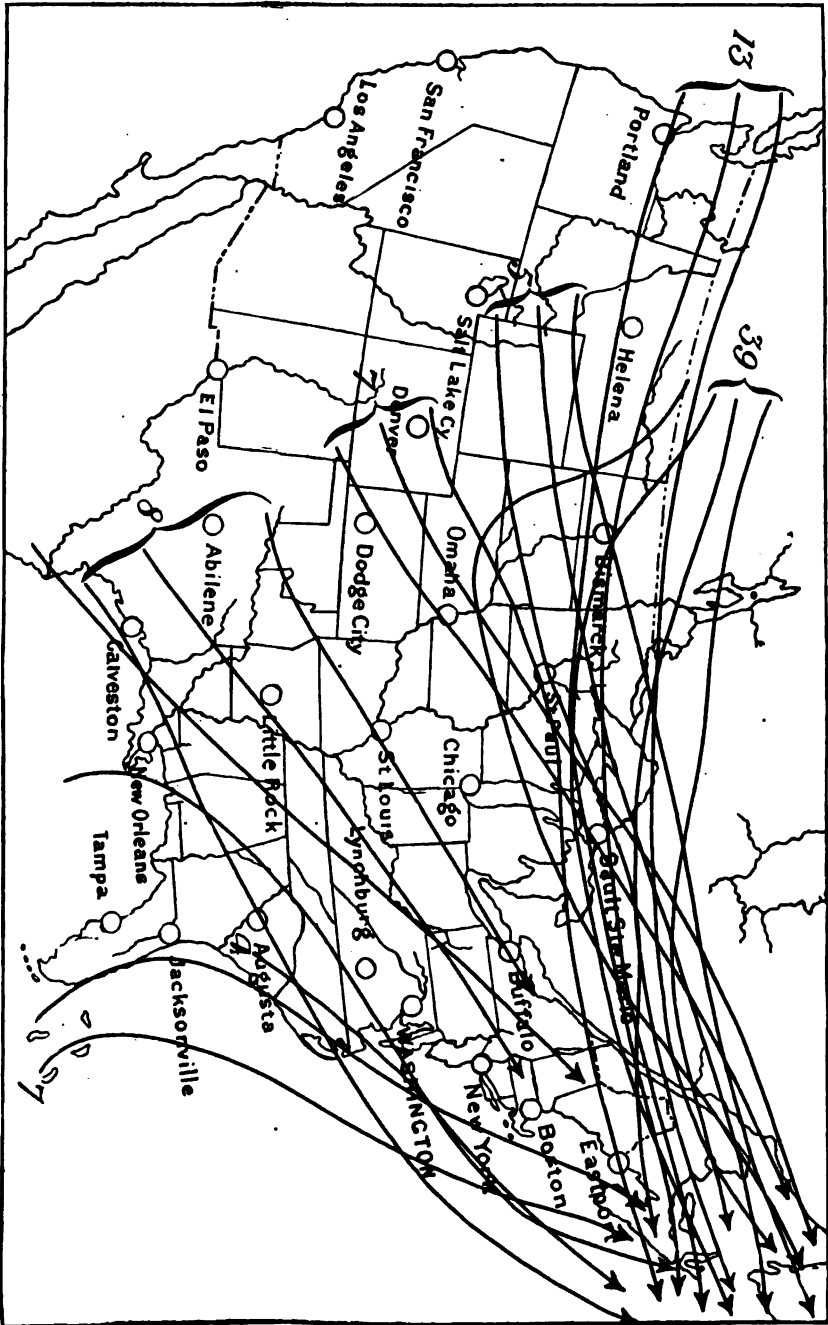


Chart 5.—Storm tracks for September.

These all pursued their paths to the Gulf of St. Lawrence, in the neighborhood of which they left the field of observation. The Alberta storms run along the northern boundary of the United States in the northwest, cross the Lake region, and advance down the St. Lawrence Valley, reaching the Gulf of St. Lawrence in about three days. It will be observed that these tracks have a strong tendency to loop down near the beginning of their paths over the Rocky Mountain slope into North Dakota and South Dakota, whence they recover the main track in the neighborhood of Lake Superior. The North Pacific storms, those from Wyoming and Idaho, as well as the Colorado storms, in twenty-four hours find themselves on the main track in the Lake region, whence they go to the Gulf of St. Lawrence. These four groups belong very clearly to one family, and have their rise on the northward side of the great high-pressure belt that extends around the globe in about latitude 30° to 35° , except where it is deflected by the continents. In the United States this belt leaves the Atlantic coast near South Carolina, but it enters this country in northern California or Oregon nearly 10° farther north. The deflection thus observed is no doubt largely due to the elevations of the Rocky Mountain districts.

On the southern side of the high belt another system of storms generates, because the air of this belt must flow off on both sides, south as well as north, though the quantity returned to the southward is less than that to the northward. Thus, we find here eight west Gulf of Mexico and Texas storms, which usually advance to the Gulf of St. Lawrence over the Atlantic States; also we have the West Indian storms, which are developed farther east, in the calm zone of the doldrums, move westward awhile in the westerly tropical current, recurve on the western edge of the great Atlantic anticyclone, hugging the periphery of the same, and also skirt the Atlantic coast, unless by the obstruction of a high they enter the Gulf States before they recurve. The erratic movements of the west Gulf and the east Gulf storms consist in their effort to break through the high-pressure belt. It is during this passage, when they are most vigorously fed, that they attain the destructive violence so often noted in the Southern States.

September is the middle of the hurricane season for the West Indies. In the China seas the season covers the same months—August, September, and October; in the Bay of Bengal there are, however, two seasons—April to June and October to November; in the Arabian Sea there are the same two seasons as in the Bay of Bengal; in the South Indian Ocean the height of the season is in January, February, and March. These differences depend upon the relations of the land and water in the Tropics, where such storms begin.

In the ten years examined the seven West Indian hurricanes recurved on the average in the longitude of the Florida peninsula. The destructive storm of September 1-7, 1888, did not recurve, but passed over Cuba westward to the Mexican coast. In 1894, September 21-30,

the storm recurved, causing serious devastation along the Atlantic coast. The primary cause for recurving or not is in the existence or nonexistence of a high area over the eastern Atlantic States. The cyclone follows in behind the high, and if this moves off to sea, opening a trough after it, the hurricane moves northward in the ordinary track. If the high hangs persistently on the coast, the cyclone is deflected far to the west before it can recurve, in which case it is likely to show very destructive qualities on the west side of the Gulf of Mexico. If rain falls freely before the hurricane comes to land, it is likely to die out; if the downpour begins after reaching land, it is probable that a long, vigorous march is yet before it.

There is much discussion in meteorological circles about the exact cause of the production of hurricanes in certain months only, and also regarding the mechanism of the whirling monsters, opinion not yet having settled upon any complete theory regarding these points. Some of the facts may, however, be reviewed, and the most probable form of the movement of the winds deduced from them. At the time of the hurricane season, August to October, the large areas of calm, sultry, and rainy atmosphere, called the doldrums, stretch from the west coast of Africa, near Senegambia, to the north coast of South America, near Guiana, in their northernmost latitudes. At the same season of the year the great Atlantic high area, on account of the heating of the continents, seems to have contracted its boundaries, and to be confined to the ocean, leaving, as it were, channels near the land, and especially on the American side. After having once started, these hurricanes hang along the border of the great ocean high, skirt its southern edge, gradually turn north on the western side, or recurve, and still following the outline of this high proceed off to the northeast, and enter the regular mid-latitude storm track. Now, the significance of the calm belt of the doldrums and the adjacent high is that the air building up in the high as it runs down feeds any vortex or whirl that may have been started along its edge, and thus continues to supply it for the many days that these violent storms are observed to last.

Some students have claimed that the tendency of the warm, moist doldrum air to rise up is the first cause of producing these cyclones. But there is one very difficult objection to overcome before this view can be established. Air will rise by convection only when the difference of temperature is considerable between the rising column of air and the adjacent regions; yet in hurricanes this difference of temperature is not observed.

Now, on examining the maps for the isobars, it is almost always seen that the lower isobar, marking out the edge of the great ocean high, has a loop or sort of pocket, by the bending down of the line, and in this the whirl begins. In the autumn, as the sun is moving southward, the impulse of the air is to follow it, and it may well be that the smooth

isobar lines stretch out fingers toward the equator, into the doldrum calm, making a pocket of lower pressure, and that herein the whirling vortex begins its course. Its future, dependent, as has been said, upon the performance of the high area in opening up a passage near the American coast, is merely the sucking in of the air from the high area, practically regardless of temperature, the rain also being a secondary phenomenon.

As to the hurricane itself when once set in motion, we have more definite information. The approach of a hurricane is usually indicated by a long swell on the ocean, propagated to great distances and forewarning the observer by two or three days. A faint rise in the barometer is indicated before the gradual fall that may become very pronounced at the center; fine wisps of cirrus clouds are first seen which surround the center to the distance of 200 miles, the air is calm and sultry, but this is gradually supplanted by a gentle breeze, and later the wind increases to a gale, the clouds become matted, the sea rough, rain falls, and the winds are gusty and dangerous as the vortex core comes on. Here is the indescribable tempest, dealing destruction, impressing the imagination with its wild exhibition of the forces of nature, the flashes of lightning, the torrents of rain, the cooler air, all the elements in an uproar, which indicate the close approach of the center. In the midst of this turmoil there is a sudden pause, the winds almost cease, the sky clears, the air is cool, the waves, however, rage in great turbulence. This is the eye of the storm, the core of the vortex, and is, perhaps, 20 miles in diameter, one-thirtieth of the whole cyclone. The respite is brief and is soon followed by the abrupt renewal of the violent wind and rain, but now coming from the opposite direction, and the storm passes off with the several features following each other in the reverse order.

By the laws of vortex motion the winds approach the center in spirals, the circular and the centrifugal movements increasing every moment. At the core, in the walls of the columnar vortex, the air circles about the calm central part, gradually rising upward to the cloud stratum, just above the inflowing disk. Here the air flows out suddenly on all sides, the circular motion decreasing, cooling by expansion, causing a great thin sheet of rain 200 or 300 miles from the center. At this distance the vortex sheet turns up suddenly, not down as usually stated, and discharges the expended vortex matter into the high upper currents of the atmosphere. If one holds a saucer of ordinary shape up and looks at it from the under side, it will not give a very incorrect idea of the general shape of this thin vortex sheet as it turns up and discharges at the edges. Over the whole underside of it is the rain cloud, in the center the ring core and the calm part.

The feeding wind lines are more nearly parallel to the ground than the upper discharge lines, but they all form a simple columnar vortex of unusual configuration. The clear sky at the center is as if a hole

were pierced in the saucer, through which the undisturbed air above alone was visible. There is probably no feature of nature more interesting to study than a hurricane, however the feelings of the observer may be affected by the experience of one at hand.

OCTOBER.

THE THREE PRIMARY DIVISIONS OF THE METEOROLOGICAL YEAR—STORM TRACKS AND WEATHER CONDITIONS FOR OCTOBER—FROST FORMATION IN THE AUTUMN.

The calendar year is capable of division into three parts as regards its meteorological conditions, and to a very considerable extent storms and other features of the weather have characteristics that closely resemble each other within these periods of time. They refer to the months (1) December, January, February, and March; (2) April, May, October, and November; (3) June, July, August, and September. The first group comprises the conditions that are dominated by low temperatures, the third those that are ruled by high temperatures, and the second the transition in October and November from hot to cold and April and May from cold to hot weather. The winter months are signalized by very turbulent circulation of the atmosphere; the rate of eastward motion is at a maximum; the storm tracks are spread all over the United States, so far disregarding their primary paths that these are nearly unavailable for classification, great alternations of temperature and pressure, cold waves, high winds, and violent precipitation being the regular features. On the other hand, in the summer months the circulation of the air is very feeble; the eastward drift is slow and illy defined; the tracks are for the most part confined to the northern border, except in the case of hurricanes and coast storms; the temperature is generally high, with small fluctuations in it, and the pressure for wind circulation small; instead of gales, only violent local storms and thunderstorms are observed.

The two pairs of transition months differ from each other in a marked degree. Thus, in the autumn, with the advance of the colder season, a sort of crispness is discovered in the air, the succession of highs and lows across the country is so well defined as to approach most closely to the typical or ideal circulation, the arrangement of all the surface winds and the precipitation is very simple, and forecasting is comparatively easy. This condition lasts until it is gradually merged into the violent outbursts of the winter, by which the chain of waves is distorted from a simple succession. In the spring the transition from cold to warm weather is one of relaxation, and an increasing feebleness or uncertainty of action takes place; many storm conditions fail to fully develop; the eastward drift ceases at times; stagnant movements of storm areas often prevail; the unlooked-for happens in consequence of a sudden intrusion of a winter storm from the north, as if the supply of cold had not yet been exhausted, and forecasting is in its most perplexing and tantalizing state.

October, then, is the first of the months to feel the approach of colder atmospheric conditions in the northern hemisphere, and if the charts are examined for their mean annual conditions it will be seen that the first symptoms of continental action in North America are present, by means of which the large permanent low pressure that covers the Arctic regions in summer is broken up into two permanent lows in winter, one central in the extreme north of the Atlantic Ocean, near Iceland, and the other in the north of the Pacific Ocean, near the Aleutian Islands. This is done by the building of a belt of high pressure over the British Possessions in the neighborhood of the Mackenzie River, which finally spreads so as to join an advancing high pressure belt from Siberia. Hence, in the United States, the high belt crosses the Gulf States to the northern Rocky Mountain slope, near Wyoming, whence one branch proceeds westward across the mountains to the Pacific Ocean, and the other branch extends just eastward of the great mountain range parallel with it to the Arctic Ocean. The Rocky Mountain region, by its lofty elevations of 1 or 2 miles, especially as a plateau, has a very great influence upon the generation of storms in the United States. Unfortunately, this region is practically unexplored by the refined processes known to science, and there is great need of planting some strong observatories in this region in the interests of meteorology, well equipped to observe the action of the sun, by means of the spectroscope, the photograph, the magnetic needle, and the telescope, in addition to the physical instruments employed by meteorologists. It is the center or heart of the circulation of the atmosphere for the United States, and yet its structure is little known at the present time.

The compilation of all the storm tracks for the month of October for the successive years shows, as in other months, that the same centers of origination prevail, the mean tracks and the number proceeding from a definite locality being given on Chart 6. It is seen that 36 storms commenced their eastward march from the district covered by Alberta, Saskatchewan Valley, and Assiniboia, or generally to the northward of Montana, whence they passed eastward over the Lake region to the Gulf of St. Lawrence; 12 set out from the northern Rocky Mountain plateau, and 11 from the middle plateau region, the former of which may be called the Yellowstone Park group and the latter the Colorado group, both of which joined the main track in the Lake region. Farther south 4 storms began in New Mexico or northwestern Texas, the tracks generally running up the Ohio Valley to the Gulf of St. Lawrence. Here we have 63 storms generating on the edge of the high plateau region of the Rocky Mountains in elevations of 5,000 to 9,000 feet above the sea level.

On the other hand, there are systems of sea-level storms whose origin is in very different physical conditions. Thus, from the North Pacific coast 18 storms entered the United States, and 3 from the South Pacific coast, the former joining the main track as soon as the mountains were

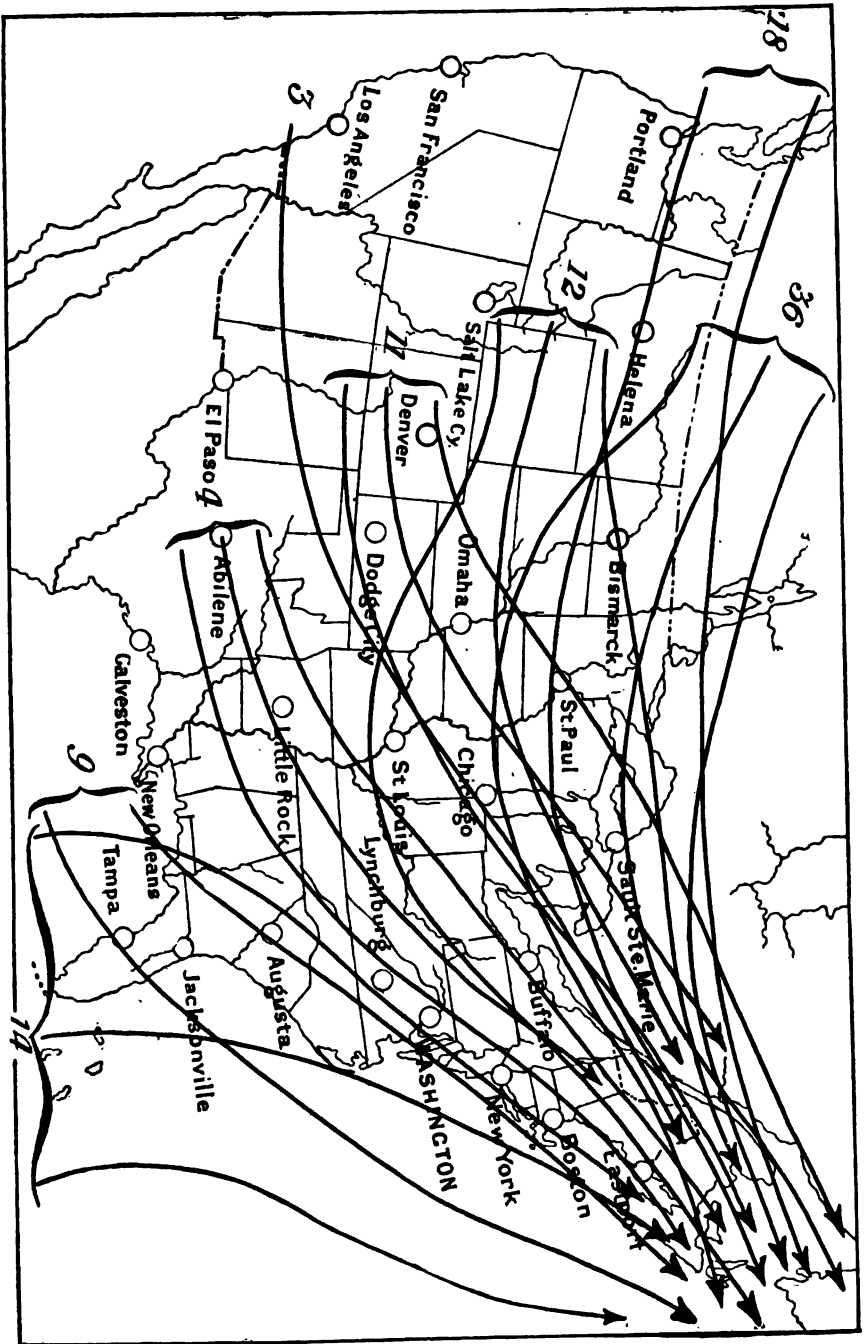


Chart 6.—Storm tracks for October.

crossed, the latter usually pursuing a track leading across the Gulf States; furthermore, there were 9 storms coming in from the Gulf of Mexico or Gulf States, and 14 West Indian hurricanes, whose tracks lay closely along the Atlantic coast. Hence, it is found that 41 storms originated at sea level and among conditions dominated by water areas. If we generalize, it may be concluded that six-tenths of our storms in October owe their origin to an elevated plateau region and four-tenths to ocean influences.

The true causes of the production of storms are so far from being understood that beyond this brief statement of the facts little that is settled can be advanced. If a similar comparison of storms originating at high elevations and at sea level be carried out for the twelve months, and covering a period of ten years, it appears that about 760 storms were generated at these high levels in the United States and about 383 at sea level; 67 per cent are therefore due to mountain regions, reaching into the high strata, and 33 per cent to ocean areas.

It is a singular fact that nearly all the observations upon which theoretical analysis has been based were made at low levels, because the facilities attendant upon civilized communities are found in the cities of the coast and the river valleys. Yet, on the other hand, the importance of attacking the problem in other quarters is very evident even from superficial considerations. When the demands of the highest science are considered, the argument for such observations is greatly strengthened.

The features of the October storms are so nearly normal that but few remarks are required concerning them. It may be noted, however, that of the storms commencing in the region north of Montana and the Dakotas, 11 dissipated in the Lake region and the remainder passed to the Atlantic Ocean north of the fortieth parallel, the average time required to reach the Gulf of St. Lawrence being about four days. The North Pacific storms have a tendency to keep well to the northward of the main track over the Lakes, after joining the Alberta path, and about two-thirds of them reach the Gulf of St. Lawrence.

October is one of the three months in which the West Indian hurricanes develop. On the international charts for ten years 1878-1887, inclusive, 16 occurred in August, 14 in September, and 17 in October, with 10 others outside these months; 14 were observed in October during the years 1884-1893. Of these, 5 came in from the Caribbean Sea, 3 appeared near the West Indian Islands, 4 apparently formed between the West Indies and Bermudas, and 2 over the eastern Gulf. The hurricane of October 11, 1887, recurved in the extreme western Gulf on the 17th, came ashore near New Orleans on the 19th, and passed over the Atlantic States to New Brunswick by the 21st; the storm of October 8, 1886, reached Louisiana on the 12th, and broke up over Arkansas on the 13th; that of October 10, 1885, crossed over Florida and the South Atlantic States, inclined westward to lower Michigan,

and thence passed down the St. Lawrence River on the 14th; that of October 10, 1893, recurved just off the Florida peninsula, moved northward to South Carolina on the 13th, and advanced rapidly into Canada on the 14th and 15th; besides these the others enumerated kept pretty well offshore in the region of the Gulf Stream. It is to be remarked that the area of recurvature covered 30° in longitude, so that no very safe rule can be stated to aid the forecaster in making his analysis of existing conditions, but it is thought that the following rule is valuable:

When a West India cyclone is moving westward in the longitude of eastern Cuba, and is north of that island, or is moving westward over Cuba or the western Caribbean Sea, it will recurve east of the south Atlantic coast of the United States when a high area occupies the northwest; and will probably cross the Gulf coast line when a low area occupies the northwest.—GARRIOTT.

The other storms of this month offer no special features, as they are generated in widely separated localities and finally march to the north Atlantic coast, unless earlier dissipated. The local storms are greatly diminished in frequency by October, owing to the colder temperature conditions prevailing from the lowest to the upper strata in the atmosphere. There has been but one group of tornadoes in five years, these occurring in Carolina within the loop of a low-pressure area; only 26 thunderstorms and 9 hailstorms were reported in the same period, no region showing any excess over the others in their production.

Heavy winds begin to prevail in certain places, Block Island and Hatteras leading, with winds above 50 miles per hour from the north and northeast; some of the Lake stations show heavy southwest winds; the stations on the Rocky Mountain slope, especially in Montana and the Dakotas, have severe northwest gales on the Great Plains, and on the Pacific Coast Fort Canby was visited by 15 wind storms from the south and west, with velocities above 50 miles per hour.

A word may properly be added regarding the formation of frost in the autumn, by which damage is often done to crops, especially the cranberry and tobacco, and to fruits and vegetables in the southern districts during the fall. Frost, as is well known, is caused by lowering the temperature of the air containing aqueous vapor till it reaches saturation, and then by further decrease of the temperature to the freezing point or below, when ice crystals of frost form on the vegetation. In the autumn this loss of heat in the air is due chiefly to a vigorous radiation from the ground, especially if the surface is dry, during the night, and it is favored by the conditions prevailing near the center of a high area, where the sky is clear, the wind very light, and the current of descending air comparatively steady. If the high drifts over a region where rain has fallen quite uniformly within twenty-four hours, the wetted surface tends to retard lowering of temperature, and will often screen a region from frost. The favorite protection, artificially available, is a dense layer of smoke from fires built on the windward side of the spot to be cared for, the effect of the stratum of smoke being

to confine radiation to its upper layers and to conserve the surface heat, by which the temperature fall will be considerably diminished. It is known that the temperatures within cities, where observations for the regular Weather Bureau daily reports are generally made, run 10° to 15° higher than in the lowlands of the neighborhood where frosts are liable. This circumstance is kept fully in mind by the forecasters when issuing frost warnings for any district.

NOVEMBER.

STORM TRACKS—WHY THE WEATHER BECOMES DRIER IN THE AUTUMN—ISOBARS AND WIND LINES IN A TYPICAL CENTRAL STORM.

It was stated in the description of the storms for October that the period of the year covered by the months October and November is the one of transition from the warm to the cold season in the northern hemisphere. These two months so closely resemble each other that nearly all the statements made for October apply equally to November, and hence an opportunity will be taken to give a more minute account of the isobars and wind lines in a type storm filling the central valleys of the United States, instead of repeating the description for November.

In the count of the origin of storms for ten years as regards locality it was found that 63 storms commenced in the elevated regions of the United States in October and 56 in November, and that 44 and 35 storms in the respective months took their rise over or near ocean areas. Putting it all together for the two months, 134 originated over the land and 79 near or over the ocean, so that the percentage is 63 of the first and 37 of the second kind. All these storms tend to advance to the point of concentration—the Gulf of St. Lawrence—and about three-fourths of them reach Washington. There they are either dissipated, or pass out to sea in the general eastward drift of the atmosphere in this latitude. It is not very definitely known what proportion of the American storms arrived at the shores of Europe, but it is not very great; and it is certain that almost every one of the western storms breaks up in the interior of the Euro-Asian continent, instead of traversing it to the eastern coast of Asia.

It is generally observed by the public that these two months embrace some of the pleasantest weather of the year, which is characterized by cool, dry air, with quite a rapid succession of alternately warm and cool or cold days. The reason for this condition is easily understood. Storms and storm tracks have been discussed and little has been said of the high areas of pressure that accompany them. It would be more accurate to say that the lows or storms attend upon the highs and are really subservient to them. At any rate, looked at from a more general point of view, a procession of highs and lows, of cold and warm masses of air, marches across the country from west to east. The lows hang

along the borders of the highs in order to accomplish the courses marked out for them.

Now, in October and November the highs originate chiefly in the continental areas north of Montana and Dakota, more so as the winter comes on, though a number of course come in from the Pacific. At this season the continent has become quite dry, as the surface evaporation has been going on rapidly since summer, and the supply from the ocean has greatly diminished in consequence of the fact that the atmosphere tends to descend from the higher strata upon the continent, and to blow thence outward upon the ocean. In other months, when the land is warmer than the water, the circulation is from the ocean to the land, and this brings in moisture with the air to keep the ground full of water near the surface. The dry highs are like sponges, ready to suck up by evaporation all surface water, but when this supply fails then the original dryness of the air is maintained as the winds blow over the country.

Furthermore, the general lowering of the temperature of the atmosphere at this season, owing to the withdrawal of the sun to the southern hemisphere, is unfavorable for the air in the lower strata to retain much aqueous vapor in suspension. If the temperature of the air is 86° F., with barometer near 30 inches, it can hold about 25 grams of water per cubic meter before saturation takes place, but if the temperature falls to 50° it can sustain only 7 grams, and if to 14° only 2 grams. Now, on inspecting the maps it is seen that in the morning we are dealing with temperatures of 30° to 50° F., and therefore dry air can take up only 3 to 7 grams of water in the cubic meter. The consequence of these two causes is to produce dry weather, and this will continue as long as the continental cooling keeps the air, on the whole, blowing toward the oceans, or as long as great high areas of dry air fill our central regions. The statistics show that the Middle and South Atlantic States, the Gulf States, the Ohio and Mississippi valleys are very dry. On the other hand, the Lake regions and New England have a large number of rainy days, the precipitation, however, being very light for the most part.

Further inspection of the maps of the Weather Bureau discloses the fact that during these two months the storms that pass over the main track, along the Lakes and the River St. Lawrence, are well formed, even strongly developed, as the high winds on the Lakes and the New England coast testify. Yet they often pass over their entire course of three days' duration almost perfectly dry.

There may be a little rain or snow in the Lake region near the center of the storm, or even in the rear of it, but no general precipitation occurs, such as the formation of isobars and isotherms and the directions of the wind suggest and would certainly produce at other seasons of the year. The dryness has been explained, but one deduction must not be omitted. The convectional theory of storms holds that the energy

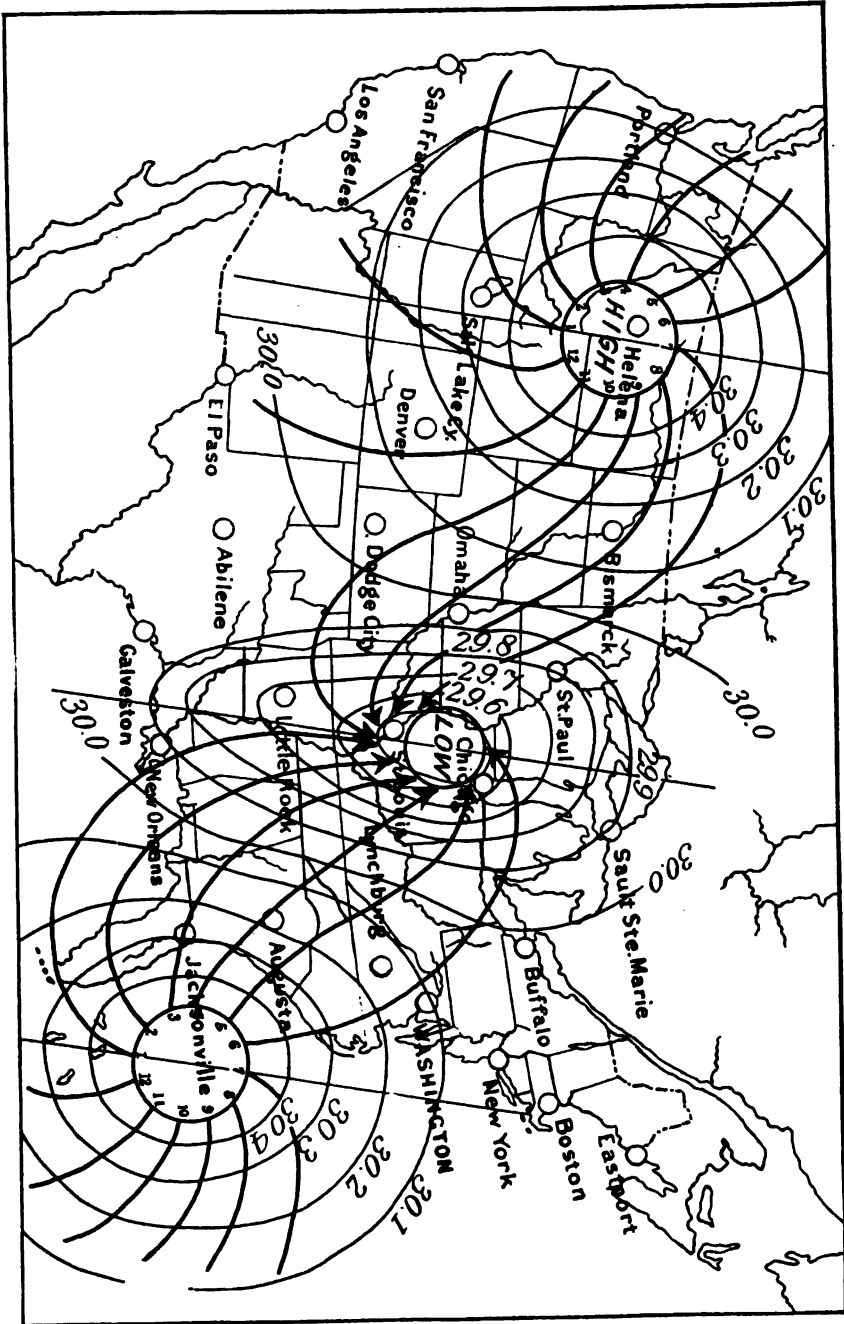


Chart 8.—Isobars and wind lines.

of storms is due to a large extent to the presence of moisture in the air, its condensation, and the liberation of latent heat with precipitation of rain. But in these months we find numberless cases of well-formed storms with deep centers, high gradients, and little or no rain, maintaining this condition for two or three days, and traversing a track of 2,500 miles in length. These facts discredit this theory of the origin of storms and relegate the function of rain to an entirely secondary position.

It may therefore not be unprofitable to examine rather closely the relations of highs and lows to each other, as shown by their isobars and wind lines.

Chart 8 has been very carefully constructed, and represents the average condition as derived from 10 fully developed storms of about this type. It was prepared to form the basis of a strict mathematical computation on the theory of storms and to put to the test some of the assumptions that have been made by writers on the subject. Starting from the center of the highs and also of the lows lying between them, every distance and angle formed by the direction of the wind as it crosses an isobar was measured, and the mean value thus found for 10 cases is incorporated on the chart. The storm is placed central in Illinois, in order to show both the contributing highs on the map of the United States, one of which covers the northern Rocky Mountain plateau and the other the South Atlantic States. This is in general a favorite location, especially for a storm covering the central valleys, and the line joining the centers lies nearly along the middle of the high-pressure belt as it crosses the continent of North America. The other configuration frequently occurring is for the western high to be located as here shown, while the eastern high lies over New England and the Gulf of St. Lawrence, but in this case the upper portion of the isobars would not be shown, as the center would lie so far to the north that they would fall outside the region of our observations.

In order to facilitate the presentation of the facts, the following system was adopted: A line was drawn through the center of the low as nearly along the ends of the oval isobars as possible, and is the axis of reference; parallel to it is also drawn an axial line through the center of the high. Now a circle was placed near the center of the high and divided into 12 parts numbered 1 to 12, the count beginning at the southern end of the axis. Then a line was drawn from the points on the circle thus marked out from the high to the low, following the direction of the wind as shown on the maps, wherever this might lead over the intervening region. The points at which these wind lines, or stream lines of wind velocity, crossed the several isobars were marked, and finally the whole chart adjusted to fit the accurate measurements. It is seen that on the western side of the high the lines 1 to 6 flow into the low, but from the eastern side only the lines 7 to 10; the lines 11 and 12 are probably lost in aimless drifting about, though the air thus unaccounted

for must finally be drawn back into the circulation. The form of the wind lines flowing northwesterly is very different from those flowing southeasterly, the former spreading out over twice as wide an area as the latter. Likewise the velocity of the wind is less on one side than on the other—that is, 11 miles per hour in the westerly moving air and 14 miles in the easterly currents, the reckoning including all the lines indicated. The relative distances of the isobars from each other on any line shows the proportional velocity of the wind between them, where the isobars are close the velocity being greater on account of the increasing gradients of pressure. Thus in the chart the wind moves fastest in the region between 30.4 and 30.2, where it flows away from the high, and between 29.8 and 29.5, where it flows into the low. An examination of the angles at which the wind lines cross the isobars shows an important difference, namely, that the average angle is 60° for the winds blowing from the southeast and 48° for the winds coming from the northwest. The spreading out, lower velocity, and greater angle on the east side of the low, with concentrated lines, greater velocity and smaller angle on the west side of it, point to a distinct difference affecting the movements of the air in these two regions. The conclusion is that the winds blow from east to west much less easily than they do from west to east in this latitude and in the United States. Both these qualifications are required, because in this latitude the upper currents of air which are intimately associated with the highs and lows all move rapidly eastward in the upper strata, and hence winds blowing against them meet with resistance; also in the United States the slope of the country is such from the Rocky Mountain plateau to the Mississippi Valley that the wind, as it were, blows down hill and is impelled forward by gravitation. From these causes our northwest winds are violent and steady near the center of the low and the southeast winds are gentle.

The primary function of this circulation is to mix the warm air from the south with the cold air from the north, in order gradually to neutralize the accumulating heat from the sun within the Tropics. These currents are in every sense transporters of the air from one latitude to another, the warm air of the south being carried north and the cold air of the north being driven south. The warm air coming from the Gulf region is charged with aqueous vapor to a high degree, the cold air from the north is relatively dry. It is seen that these two currents in different conditions of saturation and temperature encounter each other along the axis of the low, the effect being there to precipitate the vapor in the air by condensation into water. Furthermore, the air on the eastern side being warm and also being transported to cooler regions in the north, seeks to rise above the ground stratum upward, and this also causes precipitation through expansion and cooling. Thus the rain falls generally to the eastward of the axis of the low and the skies are usually clear to the westward of it.

Writers on meteorology have generally confined their discussion to certain idealized conditions, namely, circular isobars or parallel straight isobars, and based their conclusions upon these assumptions. Occasionally in very violent storms the isobars in the low may become circular, and in hurricanes or tornadoes this is usually the case; in certain parts of the system they may become straight, but this is never the case over a large area. Evidently any treatment of storms that avoids the actual facts as shown in this chart is faulty as an attempt at a complete representation of the natural movements. It is therefore hoped that the publication of this accurate chart will have a tendency to displace those artificial representations given in many text-books.

DECEMBER.

CHARACTERISTICS OF THE WINTER CIRCULATION—DECEMBER STORM TRACKS AND THE PRINCIPAL TYPES OF STORMS.

Beginning with December, and in some years with the middle of November, the very turbulent circulation of the highs and lows in the United States that is characteristic of the winter season is especially to be considered. This greater rapidity of movement and eccentricity of direction is primarily to be referred to the fact that the sun is in the southern hemisphere, so that the temperatures in the polar regions are greatly lowered and the barometric pressures increased. The Tropics are of course at practically the same temperature throughout the year, but in the northern winter the contrast in temperature between the arctic and tropical belts is relatively great, and this gives an increase of power to the thermodynamic engine which the atmosphere of the earth really is at all times. The effort of the two regions of different temperature is to restore the equilibrium that is disturbed by the solar radiation, and this is accomplished by the mechanism of the high and low circulation. There is no portion of the world where this interchange of cold and warm air is so pronounced in latitude as the United States, and this needs a very clear explanation for a full comprehension of the meteorological problem. It will not be proper to attempt to take up this extensive subject in a few sentences, and it will be therefore passed over at this point.

The turbulent winter circulation is chiefly brought into observation by the prominence that the southern circuit attains in comparison with the northern. It will be remembered that the region near the eastern crest of the Rocky Mountains in the neighborhood of Alberta and Montana is fed in by two high-pressure belts, one from the California coast and the other from the northwest British Possessions. From this junction one main path of circulation passes directly eastward over the Lakes and the St. Lawrence Valley to Newfoundland, called the northern circuit, lying directly under the axis of the great eastward upper currents, which are most vigorous in this latitude; the second mean path is along the mountain slope southeastward to Texas,

thence eastward over the Gulf States to the Carolinas, and thence northeastward to the Banks of Newfoundland. The two circuits are together like a much-bent bow, with a string uniting the ends. The long southern circuit is a product of three operations: First, the continental cooling of winter, that favors the transportation of highs from north to south before they break up; second, the circulation that builds up the tropical high-pressure belt; third, the rapid eastward drift in subpolar latitudes, that tends to draw every high back into this powerful current. The first carries the cold waves and highs from Manitoba to Texas, the second conserves them in the Gulf States, and the third draws them northward along the Atlantic coast to Newfoundland. Of course it is not easy to separate these three interacting processes very distinctly, but in winter it is not difficult to perceive their operations.

Another principle of great importance in discussing winter circulations is the fact that the so-called high and low pressure belts are somewhat inaccurately described in this manner. From mathematical analysis it is shown that the atmosphere circulates in such a way as to tend to accumulate with high pressure on the outer edges of the Tropics, near latitude 35° north and south, and at the same time to make a sub-arctic low-pressure belt near the latitude 55° . But, as a matter of fact, continuous high and low pressure belts do not exist. In place of them there is a succession of highs and lows passing over these tracks, the air tending to mass itself in nearly circular areas, alternately cold and warm, from which the observed wind circulation is derived. In the order of natural cause and effect the highs come first and the lows follow, and not in the opposite sequence. Masses of cold air are built up in the high-pressure belt by the effect of general atmospheric motions, the air descending from the upper strata. Between two adjacent highs, and also all around the periphery of a large high, the lows are formed by the action of gravitation, which throws the currents into whirls. These have the effect of forcing the air back again into the upper strata, where it flows off in the general eastward drift. The highs are made up of air descending through at least 5 miles of strata; the lows, on the other hand, are forced up about 2 miles, where they are nearly obliterated by the upper currents. The notion that the highs are fed chiefly by the lows, or that the lows are the primary source of the circulation, has but little foundation, the attempt to make the storm energy do so much work having failed to find the necessary support in modern observations. Having thus sketched the general features of the circulation in the United States for the winter months, we may examine in some detail the facts as given by ten years of the records of the Weather Bureau for the month of December.

The number of storms originating near Alberta and Manitoba for the years 1884 to 1893, inclusive, was 49; entering the United States from the North Pacific coast, 28; forming on the northern Rocky Mountain slope, 10; near Colorado, 14; in Texas, 8; in the Gulf States, 8; to the

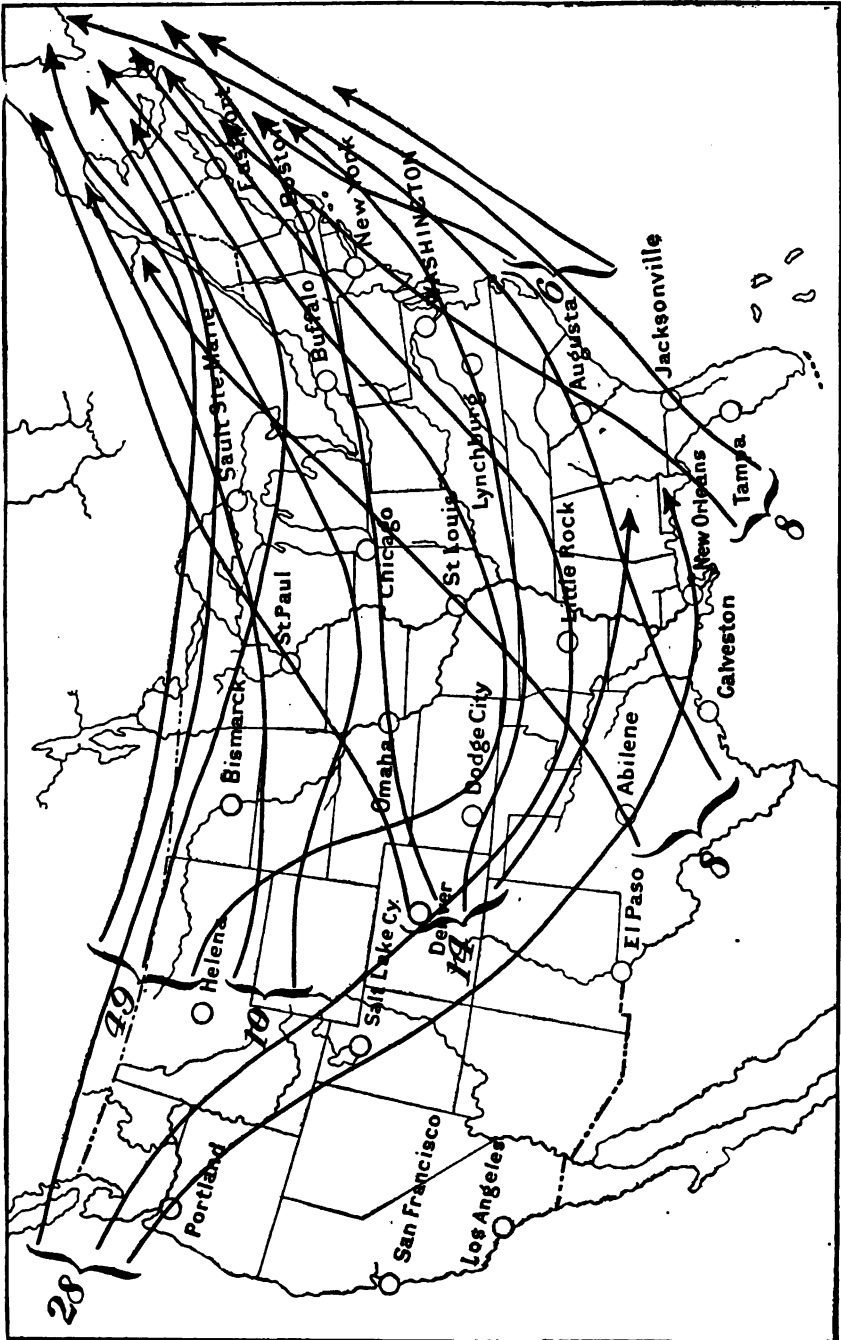


Chart 9.—Storm tracks for December.

east of the Atlantic coast line, 6. Setting aside the North Pacific group, which has a somewhat different history, it may be noticed that the places of formation of the storms just mentioned lie on the great curve that is called the southern circuit. Wherever they form, the track they primarily seek to pursue is one leading directly toward the Gulf of St. Lawrence, where they are caught up in the great eastward current and drawn out over the North Atlantic Ocean. The abnormal tracks are in nearly all cases caused by the rapid march of a high from north to south, while the low clings to its edge, being fed as it gyrates, while it seeks to swing from the south to the north side of the high. When doubt exists in making a forecast, the general principles here enunciated are of great value in deciding what the course of events will probably be. These principles, namely, the interaction of the two primary circuits and the dependence of the lows upon the highs, will probably be found more efficacious in forecasting than the study of types so generally in favor with American meteorologists.

The Alberta type.—When a low forms in the extreme northwest, it is generally found that another low covers the Gulf of St. Lawrence, and that an extensive high area occupies the central valleys and the Gulf States. The center of the high will probably move slowly eastward to the Carolina coast, and thence work northeastward over the ocean. The Alberta low advances in one of two paths: (1) to eastern Dakota in one day, to Lake Superior in two days, to the middle St. Lawrence Valley in three days; or else (2) it will be deflected southeastward to Iowa and Missouri in two days, whence it will make Lake Ontario in one day more. About one-third of the storm centers will be deflected into the southern course, and these are much more erratic in their action and harder to forecast.

The North Pacific type.—These come in over the extreme northern coast, near Vancouver, and separate about equally in numbers into two paths, of which the first is directly eastward over the Lakes and the second far to the southeastward along the mountain slope, generally reaching northern Texas. In this case a high covers the central valleys and the Missouri Valley, the weight of it being near the northern boundary, whereas in the Alberta type it was heaviest in the Gulf States. There will usually be found three lows in sight, one over the North Pacific, one over the Gulf of St. Lawrence, and the third over Florida. It is evident that these are being fed and sustained by the great high, all in the same way and independently of one another, though each is in intimate subordination to the high. The course of the Pacific low will be determined by the movement of this high. If the high passes directly eastward in the northern circuit, the low will follow behind in the northern path; if, on the other hand, the high seeks the southern circuit, the low will maintain about the same relative position, but the tracks will now lie to the southeast over the mountain slope and the Gulf States. It is therefore of primary importance to

know, in making a thirty-six-hour forecast, which circuit the high itself will take from the Dakotas. If it goes east, the low will move to North Dakota in one day, to Lake Huron in two, and to the Gulf of St. Lawrence in three days; if the high moves southeastward over the Ohio Valley, the low will be found near Colorado in one day, in the Lower Mississippi Valley in two days, and if it survives, in the St. Lawrence Valley on the third day; some storms of this type have crossed the Gulf States to South Carolina, and have thence moved along the coast line to the northeast. The storms taking the southern track, it is seen, travel with great rapidity, making the long path in the average time of about three days.

The Colorado type.—This is a marked type of storm, forming in the neighborhood of the Colorado mountains. The disposition of the highs is of a very different sort in this case from that of the preceding types. Now one strong high covers the south Atlantic and eastern Gulf States, and a second covers the north Pacific States and the northern Rocky Mountain region. The latter high lies at the junction of the two circuits in the northwest; the former on the axis of the circuit in the southeast; the Colorado low forms in between them, where the counter flow from the highs causes a cyclonic gyration. The northwestern high moves from the California coast southeast to New Mexico, or else farther north to southern Minnesota, in about two days.. The Florida high moves northeast along the coast to New England in the same time. The entire system therefore shifts along the southern circuit. Meanwhile the storm moves in a very regular course northeastward in one day to Illinois, in two days to northern New York, and in three days to the Gulf of St. Lawrence.

The Texas type.—In this case the formation is similar to the Colorado type, the whole system, however, being somewhat advanced along the southern circuit. The eastern high is now central on the Carolina or Virginia coast, and covers the districts east of the Mississippi River; the western high is well to the east and covers the Rocky Mountain slope, being central near Wyoming. Between these a low area is found central in Texas, or near the west Gulf coast. The circulation now carries the Atlantic high northeastward to Newfoundland in two days and the Pacific high to Arkansas in two days. Meanwhile the Texas low moves rapidly northeast over the central valleys to Indiana in one day, to northern New England in two days, while in three days it will disappear from the map.

The Gulf of Mexico type.—The description of this type is about the same as for the two preceding, except that the system is again advanced to the east. These three types show distinctly the same fundamental relation to the southern circuit, being transported farther along from one stage to the other. Finally there are a few sporadic Atlantic coast storms, forming near the Gulf Stream and moving northeastward to the end of the northern circuit, near the Gulf of St. Lawrence. It should be

remarked regarding all the lows generated in the southern circuit, especially the Texas and the Gulf of Mexico type, that they make some of the most severe storms that sweep over the Eastern States. The Gulf States still retain much of the heat and moisture peculiar to the summer season, while the highs from the northwest are vigorous with fresh, cold air. This combination is very favorable to the formation of sudden, rapidly advancing storms, with heavy precipitation, violent winds, great contrast in temperature on the eastern and western sides. The early heavy snowstorms of the Eastern States usually come from these southwesterly winds, and their passage over a district is almost sure to be followed by a destructive cold wave, which, if unseasonable or unusually persistent, causes great damage in the southern portion of the Gulf States. The warnings of the Weather Bureau are particularly valuable in the case of these storms, especially in anticipating violent winds and high temperatures, to be followed by very marked cold waves and freezing in the Southern States.

The central high type.—There is one more formation very characteristic of this season. A large high area sometimes covers the entire country from the Pacific to the Atlantic, giving clear, dry weather for several days in succession. The high holds quite steadily, the isobars being north west to southeast, or even directly west to east, and it finally drifts off in an irregular manner, and is followed by a low in the extreme northwest.

The system of movements thus enumerated for December prevails quite steadily till March, when it begins to disintegrate in some very irregular and abnormal motions for April and May, introducing the summer circulation which is confined to the northern circuit. Forecasting in the winter deals with rapid movements, great alternations of temperature, and the interplay between the two primary circuits; in the summer it is confined to the northern circuit, while sporadic local storms, tornadoes, and thunderstorms take the place of dominating cyclonic actions.

JANUARY.

IMPORTANCE OF THE NORTHWESTERN DISTRICTS—STORM TRACKS—TEXAS STORMS—COLD WAVES.

Most of the weather conditions described in December continue to operate in January, but with somewhat greater intensity. The turbulent changes in the atmospheric circulation are more pronounced, and the alternations of fair and stormy weather more decided. This is due to the fact that lower temperatures exist over the entire arctic cap of the northern hemisphere, while at the same time the atmosphere within the Tropics is maintained nearly at summer heat, so that a very rapid change in the thermal gradient occurs in going south or north along any meridian. Accompanying this fall in temperature with the latitude, the pressure also is relatively much altered in the summer and the

winter distribution, such that in summer a large, nearly permanent low area covers the arctic zone, while in the winter this is divided into two low areas by a comparatively high belt crossing the arctic region. These lows are central, one near Iceland and the other near the Aleutian Islands, while the high belt passes over the British Possessions near the Mackenzie River Valley, northern Alaska, into northern Siberia, whence it goes southwest to unite with the high pressure belt of the temperate zone. The tendency to accumulate masses of cold dry air in the British territory between the Rocky Mountains and the Great Slave Lake region, just east of them, is of special significance in the study of the weather of the United States in the winter. Since the high-pressure belt thus described lies athwart the course of the current of eastward drift that prevails in the upper strata, it is inferred that there is an effort going on to break up the formation of any continuous area of high pressure in the arctic zone, so that these masses of air are intermittently broken off to drift eastward in the northern circuit or southeastward in the southern circuit. Inasmuch as the passage of a large high area is accompanied by a cyclonic circulation, or low, on the front and also on the rear sides, or, in other words, by areas of warmer air on either side, it is seen that this condition tends to produce rapid changes in the temperature of the air that is thus moving eastward over any district.

This northwest region is of especial interest in the meteorology of the United States, for it is practically the heart of the circulation of air that passes eastward, and if it is possible to fully understand the action of the forces operating there it will become much easier to generalize safely concerning many other problems in the physics of the atmosphere. It may therefore be proper to present a few statistics regarding the northwest region. Unfortunately we possess no suitable observations in the exact region where the center of operations is located, between the Great Slave Lake and the mountains, that are continuous over a series of years. It is found, however, that the conditions there generated drift forward to the Dakotas in about one day, on the average, so that, utilizing the observations of the Weather Bureau in those States since 1878, we can form a definite idea of the facts that are involved in the problem. The record of the seventeen years, 1878-1894, gives the following results for the contrast between summer and winter: The mean summer pressure of the Dakotas is 29.90 inches, and the temperature is 67° ; the mean winter pressure is 30.14 inches, and the temperature is 10° ; winter includes December, January, and February, and summer, June, July, and August, for these conditions. The mean annual pressure is 30.03 inches, and the temperature is 40° , the change being twenty-four hundredths of an inch and 57° F. These are the annual mean values, and of course imply much wider ranges on individual dates.

Now, on examining the changes from day to day in the pressure and

temperature, or, as they may be called, the amplitudes of the warm and cold waves passing over the Dakotas, it results that the barometer swings up and down on the average of thirty-five hundredths in winter and nineteen hundredths in summer, while the temperature oscillates on the average about 20° in winter and 8° in summer. These variations are due to the highs and lows passing over those States, and are made up of all the observed changes, large and small, that occur in this connection, some being wide and some very slight. It would be nearly correct to double these figures in order to obtain the wide individual changes that can be noted. It is the passage from the summer values to those of the winter that makes up the seasonal changes, and when these are translated into the winds, gales, hot and cold days, as they come one after the other, it will easily be inferred what a power these small numbers really represent in the action of the earth's atmosphere. In the Tropics, by way of contrast, the amplitude changes are not one-fifth as large for the year. The question naturally arises, What is the exact action or energy in nature that causes this vast accumulation of forces to take place in the region to the northwest of the Dakotas? This is peculiarly interesting from the fact that there is no other region known in the northern or southern hemispheres where so great an output of energy is observed.

The peculiarly rough type of weather prevailing in the United States during the winter as compared with Europe or even Siberia is entirely dependent upon it. There are doubtless a large number of causes at work to bring about this result, yet it is possible to specify some of them, and this will be attempted in connection with the February storms, when this set of influences rises to the maximum power.

The stormy conditions thus generated in the extreme northwest are propagated eastward in a series of irregular, spasmodic discharges, or storm drifts, that cover the United States, the intensity diminishing gradually as the storm power becomes exhausted on the way to the Atlantic coast. The belt of the Northern States lying under the great eastward drift current is swept by these violent changes nearly all the winter; not infrequently these are projected so far south as to reach the Gulf States with gales and cold waves. The storms forming in the Southwestern States, near Texas, are in reality the effect of the work done to the northward in Manitoba, the activity of a single storm covering many thousand miles when the interchanging winds of the highs and lows are considered.

Conspicuous features of the distribution of the origin and the tracks of storms, when the months of the year are compared with one another, are the facts that as the winter approaches the number of storms forming in the Southwestern States increases decidedly, and that the tracks loop southward over the Rocky Mountain slopes. In the months May to December the average number of Texas storms is 6, but in the months January to April it is 17, for each month, as a total for the ten

years 1884-1893. The effect of this is to cause many more storms to cross the south central valleys, the Gulf, and the South Atlantic States; also the storms beginning in the northwest are often forced south-eastward to the Gulf States before they recurve to the Gulf of St. Lawrence. These effects are apparently due to the great highs forming to the north of Montana, which are driven forward to the south and propel the storm in front of them in the tracks just indicated.

An examination of the types peculiar to the several districts gives rise to the following data for January: In the ten years discussed there were 98 storms, 32 belonging to the Alberta type, 20 to the north Pacific coast type, 8 to the north Rocky Mountain plateau type, 10 to the Colorado type, and 21 to the Texas type; 2 others formed on the south Pacific coast, 2 in the eastern Gulf, and 3 near the Ohio Valley.

An examination of the international charts regarding the causes producing storms in the Saskatchewan Valley shows that they are usually preceded by a loop from the Alaska low intruding upon this region, which is then broken off by the action of the highs in the neighborhood. It is seldom that any distinct gyratory movement of the wind is seen around an advancing center, until the loop is in the valley east of the mountains, as far north as 50° to 55° latitude. If the same cause operates more to the south, in latitude 45° to 50° , then a true cyclonic low is formed over the ocean and advances upon the coast as one of the North Pacific type. These two types, forming under the same general conditions, embrace more than one-half of all the January storms. Two-thirds of these reach the Atlantic coast north of the fortieth parallel, and if they move in the northern circuit over the Lake region the succession of warm and cold, stormy and fair days will be very regular. If they are, on the other hand, deflected southward, the probable course of the track is harder to determine, the rate of advance and the severity of the storm will be more difficult elements to include in the forecast. The average velocity of eastward movement is 37 miles per hour. About two-thirds of the storms of the Alberta type move eastward over the Lakes, but one-third are deflected as far southward as Missouri, that being the average place of turning northeastward.

In a similar way about one-third of the North Pacific coast storms bend southeastward to nearly the same latitude, 37° , but they recurve farther to the west in the States of Colorado or Kansas. The tracks of this type are much more spread out after crossing the mountains, but they generally make the lower Lake region and advance down the St. Lawrence Valley. An important feature regarding the precipitation of the storms moving in the northern circuit is that before the center reaches the Upper Mississippi Valley the fall is on the western or following side of it in Montana, the Dakotas, and Minnesota; but within a few hours the precipitation is transferred to the eastern side of the center into the Lake region, and then advances before it over the

Middle States and New England. It is hard to include such facts in the theory that rain or snowfall is essential to the formation of storms or that lows advance to the region of greatest precipitation. The order of events seems rather to be that the lows are products of the highs, and the precipitation effects of the lows.

In point of number and in severity of the winter storms the Texas type stands in the front rank, and deserve particular attention from the forecaster. Some of them form in northern Texas, near the terminal slopes of the mountains, and they usually advance to lower Michigan and reach the Atlantic Ocean in about forty-eight hours. Others originate in southern Texas, and these are likely to move more to the eastward over Tennessee and Kentucky, along the Appalachian range, the march from Texas to New England taking about two days. Still others form in the western Gulf or near the Rio Grande River, and these are usually found to skirt the Gulf and the Atlantic coasts and to reach the New England coast in forty-eight hours. In general, immense areas of rainfall accompany these storms, covering the Lower Mississippi Valley and the Ohio Valley in twenty-four hours, the Atlantic and New England States in the next twenty-four hours. The rise of temperature in the front is excessive, and the passage of the storm is likely to be followed by a severe drop in the temperature, with a cold wave in the Southern States and clear, dry weather.

The northern and southern types now mentioned comprise three-fourths of the January storms, the others being sporadic or else abnormal, and depending upon the relative location of the high areas and their movements. One of the South Pacific storms moved northeastward to the Lake region and the other directly eastward to the South Carolina coast; the 2 east Gulf storms followed the Atlantic coast line to the north; the 3 Ohio Valley storms moved to New England. The northern Rocky Mountain (8) and the Colorado (10) storms all moved with great regularity to the northeast, except that the former generally looped southward into Nebraska.

The cold waves of the winter season, setting in during the second half of November and continuing until April, are important matters for the attention of the Weather Bureau.

For forecast purposes in connection with cold waves, the country east of the Rocky Mountains is divided into five districts, according to the relative frequency and intensity of the waves; the region most marked in these respects embracing the Northwestern States, and that least marked including Florida and the Gulf coast.

The temperature falls required to constitute a cold wave vary with the districts and the seasons of the year, but range from 24-hour falls of from 20° to 16° with minimum temperatures of from 16° to 32° during the months of December, January, and February, to the same 24-hour falls with minimum temperatures of from 20° to 36° during the remaining portions of the year. In verifying a signal ordered to forecast a cold wave these conditions must be fulfilled.

Cold waves come with the quick advance of a high area from the north, and they are materially strengthened by the passage of a vigorous storm center northeastward along the edge of the high, the latter tending to raise the temperature in the front and the former to depress it decidedly in the rear. It is often a very difficult matter to mark out successfully the exact boundary of this extreme fall of temperature because the rapid changes in the relative places of the highs and lows can not always be definitely foreseen. In spite of this the Bureau is able to give such timely warnings of sudden drops of temperature as to be of great value to the transportation and commercial interests of the United States.

FEBRUARY.

IRREGULAR RATE OF EASTWARD DRIFT OF STORMS.

Under the month of January an attempt has been made to direct attention to the importance of the northwest region in the meteorology of the United States. On the eastern slope of the Rocky Mountains, in the Canadian possessions, in the neighborhood of 115° west longitude and 55° north latitude, there exists a peculiar mechanism whose work is to turn out a series of highs and lows, following each other in an apparently fortuitous sequence, which then advance over the United States in the tracks that have been described.

The leading feature in the meteorology of the earth is the fact that the sun's radiation warms the tropical and temperate zones, leaving the arctic regions cold. From this unequal temperature there are produced convectional currents, of which the primary are the tropical trades blowing westerly and the upper current in the temperate zones blowing easterly. The movements of our highs and lows have much to do with this eastward current, and upon it depends the main eastward drift that is at the basis of the practical forecasts of the Weather Bureau. The most remarkable feature regarding this eastward drift, over the entire hemisphere, is that sometimes it is very rapid and at other times very slow, the acceleration and the stagnation succeeding each other at uncertain intervals.

This irregularity is, on the whole, the most difficult feature in forecasting to take account of, and on account of it occur many of the failures. A sudden slowing up of the drift will necessarily throw the whole forecast into confusion, and an unexpected rush will also produce disaster. This peculiar change in rate of motion seems to occur simultaneously over the two continents and the two oceans, and is therefore probably due to the work of some great cosmical agency, a discussion of which will be found later in this paper.

The tracks for February are similar to those for January and March, and much of the analysis of storms is equally applicable to these three months. The intensity of the weather conditions gradually rises from

September till it culminates in February, and thence falls off till June, when the summer relations become reestablished. A count of the number of storms in February for ten years 1884-1893 shows that 27 originated near Alberta, 18 on the North Pacific coast, 8 on the northern Rocky Mountain plateau, 13 in Colorado, 18 in Texas, 6 in the east Gulf and South Atlantic States, 7 in the central valleys, and 2 on the South Pacific coast, making a total of 99, and averaging 10 each month.

Approximately 20 per cent of our February storms come from the Pacific Ocean and States, 24 per cent from the Gulf of Mexico and Gulf States, and 56 per cent are developed in the interior. The tracks converge, as usual, to the Gulf of St. Lawrence, when the movement is normal. The anomalous tracks usually have a decided loop southward along the Rocky Mountain slope, whence they may advance and be lost near the Gulf of Mexico or recurve to the Lake region and the St. Lawrence Valley. These storms almost always move in front of a large high area, whose rapid and vigorous movement thrusts the northern storm to the southward before they can gyrate to the east front along the periphery of the high.

The Texas storms, as in other months, are rapid marchers, and are attended by widely extended rain or snow precipitation. If there is no high over the Gulf of St. Lawrence which retards the northeastward movement, they reach New England in forty-eight hours; if a high hangs persistently in that region, they may require ninety-six hours. If a high is located in the northwest, threatening a cold wave, this will reach the Gulf States if the movement is rapid; it will be dissipated in rain or snow if the low is much retarded. Special attention should be directed to the probable behavior of the St. Lawrence high, as upon this will depend success in forecasting the advance of a large storm from the southwest.

MARCH.

THE BREAKING UP OF THE WINTER CONDITIONS AND THE WIDELY SCATTERED SYSTEMS OF STORM TRACKS.

March impresses itself upon the dweller in the northern half of the United States as a particularly windy and disagreeable month, with strong alternations of wintry and mild weather. This is due to the breaking up of the conditions that have prevailed since December, and the processes of return to spring and summer. There is in the Arctic zone an enormous amount of cold material to be disposed of, covering the northern regions in the form of ice and snow; at the same time the southern zone is becoming decidedly warmer in consequence of the advance of the sun to the northern side of the equator.

The United States is peculiarly the theater of this contest between the giants of cold and heat, and they stagger back and forth over this territory as one or the other is for the time being in the strongest form. The cold waves launch themselves from the North and carry

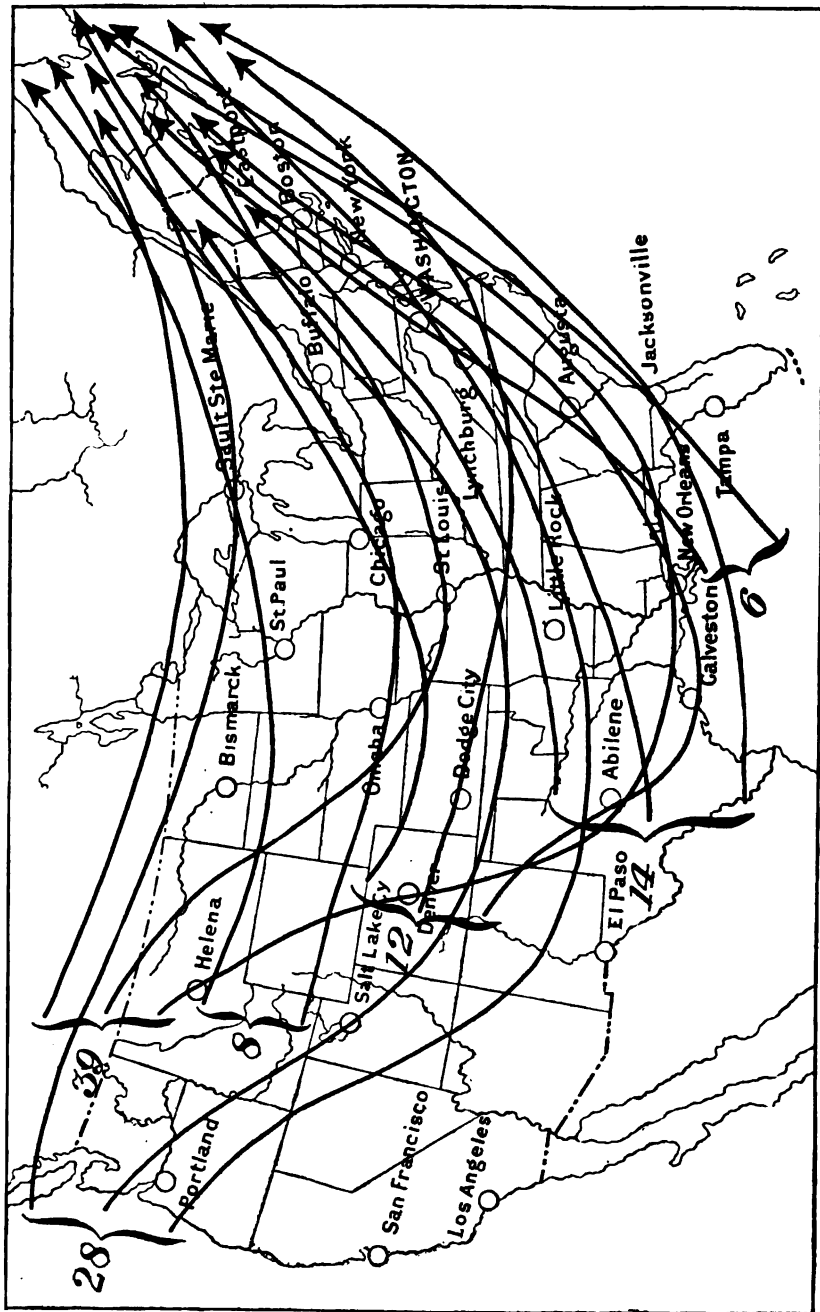


Chart 12.—Storm tracks for March.

their icy chill to the warm Southern States; or, on the other hand, the warm currents of air from the South advance far into the North, and this alternation causes a rapid variation in the temperature and the other weather conditions at stations of the middle latitudes.

An examination of the storm tracks for March gives very definite evidence of the effect of this struggle for supremacy. Instead of being confined to the neighborhood of the mean tracks, it is found that they spread out over the entire territory of the United States from north to south. The phenomenon of looping southward along the Rocky Mountain slope before recurving northeastward to the Gulf of St. Lawrence is most pronounced.

The storms which first develop in Alberta or on the North Pacific coast may advance directly eastward over the Lakes to the Gulf; or they may be pushed south and recurve in Colorado, Missouri, southern Illinois, or southern Indiana, in order to move to the St. Lawrence Valley; or else they may be propelled still farther south along the Rocky Mountain slope to Texas and the Gulf coast, whence they proceed to the South Atlantic coast, and then turn northward to Newfoundland. Not a few of these storms dissipate in the Lake region or the Ohio Valley; others will persist in a path of nearly 5,000 miles, from Alberta to southern Texas, South Carolina, and finally to Newfoundland.

It may be asked, What is the primary cause of these very widely scattered storm tracks in March, as compared, for example, with the regular distribution of those noted in October? The answer is clear and comprehensive. It is that the lows, or storm centers, are in all cases developed along the edge of the high area, and that they depend on the high for the source of the great volume of air that circulates through them, and to which the motion peculiar to the configuration of the low is due. As the high moves, so also moves the low, partaking of its eccentricities as to direction, rate of motion, and distance of propagation. If a high forms on the great plains of the British Possessions under the magnetic auroral belt, just eastward of the mountains, a low will also at the same time develop to the south of it, in Alberta or Manitoba. As the high is driven southward it may work into the central valleys, holding the low still to the south, by which time it will mark out a track southeastward to the Gulf States; then the low will gyrate along the front and eastward side of the high, which may halt or dissipate in the South Atlantic States, while the low, still drawing its supply of air from the high itself, advances northward and is taken up by the great eastward current of latitude 45° to 50° . The unequal distribution of the tracks of the storms in March is therefore due to the irregular propulsion of cold masses of air from the Arctic regions into the middle of the North American continent.

A peculiarity of continental action is that in summer the interior is warmer than the borders, but in winter the interior is colder than the coasts. The upper Lake region and the Upper Mississippi Valley are

especially remarkable for this feature. Between meridians 95° and 100° and between parallels 50° to 55° the change in temperature is the greatest known in North America. It is coldest in winter there, and also it may become the hottest part of the country in summer; the range of temperature may be from 45° below zero in winter to 105° above zero in summer, a change of 150° . The encroachments of spring upon the winter in North America proceed from the extreme southwest, the Gulf of California, and the Colorado River Valley, and advance toward the northeast. There is constantly going on a vigorous interplay between the cold pole in the Red River Valley of the North and the heat that is working in from the lower Rocky Mountain plateau and the extreme southwest.

This leads to a description of one of the most characteristic features of the advance of the summer upon the North American continent. In winter the lines of equal normal temperature, that is, the isotherms, are grouped about the cold pole in quite a symmetrical manner, bending southward in the interior as they pass from the Atlantic to the Pacific coast. This configuration may be regarded as normal from November to March, inclusive.

In summer the formation is somewhat inverted, the lines bending northward from the coasts toward the interior, though the crest is now farther west, in the dry Rocky Mountain region. The Gulf of California is the central region of heat, and the crest extends from Yuma, Ariz., northeastward toward the Dakotas. This inversion of the crests of the isotherms in the interior of the continent is necessarily accompanied by a notable change in the configuration of the areas of equal pressure.

When the winter cold is established the high-pressure belt is very firm in the Rocky Mountain districts, and is shown by a persistent high area in that region, which may linger many days, with apparently no active effect upon the weather conditions in the central valleys, and it is therefore called a "dead high." This western high is often a well-established feature from November to March. During September and October conditions favorable to the development of this high are improving, and during April and May their destruction is taking place.

In the summer this permanent high is replaced by a trough of low pressure, extending from the Gulf of California, where it is always lowest, along the plateau region to the Dakotas. At that time a more or less permanent high is located on the northern Pacific coast, and another is central in the east Gulf States. The cause of the formation of these different types of highs, as modified by continental action, is one of the most important problems presented to meteorology for solution, but, unfortunately, our knowledge of the physics of the subject is very imperfect.

The transition of the winter high of the Rocky Mountains to the summer low is indicated by a peculiar change that should be consid-

ered. The first sign of the coming modification is that the high area is flatter, covers a wider territory, especially on the northern plateau and slope, and is less likely to build a marked center in the neighborhood of Utah and Wyoming. The second symptom of the change is that the center of the high slides gradually to the northeastward, passing over the Dakotas to the upper Lake region. Another way of stating the same fact, as shown by the normal charts extending over twenty years, is that the axis of the polar high pressure, which is tributary in the winter to the mid-latitude high-pressure belt, gradually works eastward from near the base of the mountains in western Canada to the shore of Hudson Bay, and bends so far southeastward as to discharge to the east of the Lakes instead of to the west of them in the Upper Mississippi Valley. This change produces a very different aspect on the map for the purpose of forecasting. When the discharge from north to south is along the Rocky Mountain slope, the formation of storm centers, and the axis of cold waves is usually in the Missouri and the Upper Mississippi valleys; but when the output from the Arctic zone is to the eastward of the Lakes, then the western region is comparatively flat and quiet, but the cold waves and the high area from the north are projected into the Lake region and New England. These often come very suddenly, and almost without preliminary indications on the charts, being usually accompanied by a low center in the Gulf of St. Lawrence, upon whose western quadrants the high advances rapidly. There are several weeks, especially in March, when an uncertainty exists regarding the axis of the Arctic high, whether it be to the west or the east of the Lakes, and this causes great confusion in the tracks when collected for a number of years on the charts. In April and May the high has moved so far eastward, nearly to Hudson Bay, as to make the majority of the movements from the north occur to the eastward of the Lakes. In the meantime the low trough has advanced so far from the extreme southwest as to make itself the dominant feature of the Rocky Mountain districts; hence the forecasts of cold masses of air for the Middle States and New England become the leading feature for consideration, and in fact the attention of the forecaster is necessarily fixed upon this region.

A count of the number of storms originating in the several districts shows that Alberta is to be credited with 39, the North Pacific coast with 28, the northern Rocky Mountain plateau with 8, Colorado with 12, Texas with 14, and the east Gulf States with 6, making a total of 107 for the years 1884 to 1893, inclusive. The Alberta storms move in part along the northern circuit, some loop down the mountain slope to Colorado, and others reach Texas before recurving to the northeast. The North Pacific storms show an even greater tendency to loop southward to the west Gulf States, though some move directly eastward, and others take a middle course between these extremes, the result being to cover the western region with the tracks. The Colorado

storms are also inclined to loop southward, and the majority of them cross the Gulf States to the Atlantic coast before moving northeastward, although a few may pass over Lake Michigan and the lower lakes. The Texas storms almost invariably move eastward at first, a part of them taking the interior track westward of the Alleghany Mountains, the remainder following the coast line from North Carolina to Newfoundland. The storms that originate in the middle Gulf States generally touch the middle Atlantic coast near Virginia or North Carolina, whence they pass northward over New England. As in other months when the Gulf of Mexico or Texas storms are attended by heavy precipitation, they are likely to produce widespread and even disastrous effects in the shipping ports along the Atlantic coast. It takes about forty-eight hours for such storms to reach New England, unless decidedly retarded by a persistent high in the St. Lawrence Valley.

It may be observed that the magnetic auroral belt runs directly along the region from which the high advances, whether the discharge be from the western or the eastern side of the Lake region.

The magnetic force seems to be efficient in producing meteorological effects in proportion as it can operate in cold atmospheric conditions. Hence the encroachment of warm air from the southern Rocky Mountain districts as spring comes on is unfavorable for this kind of action, and it seeks to transfer its seat to the portions of the interior of the continent that still retain low temperatures, namely, to the Hudson Bay districts; finally, as the summer heat conquers this cold territory, the winter high passes away entirely, and the whole arctic region is covered by low pressures, extending from the north Atlantic to the north Pacific Ocean and passing directly across the Arctic Ocean.

The unsettled weather of the month of March, especially in the northeastern portions of the United States, with its rapid alternations of warm and cold winds, often reaching considerable violence, is therefore the parting salute of the cold winter that has prevailed for five months throughout the northern cap. A most impressive feature of this change, as deduced from a close study of the barometers and temperature readings of the Weather Bureau, is the suddenness with which the struggle is concluded in the northwest, for March often comes in with a very violent action, and this is almost certain to end about the 20th of the month with moderate movements of the air. The struggle is prolonged in the east, but is usually about over by the 10th of April.

APRIL.

FORMATION OF THE ROCKY MOUNTAIN LOW—CAUSES OF RAINFALL—STORM TRACKS—FROSTS IN SPRING.

The weather conditions prevailing in April indicate a transitional state between the winter and summer seasons, with the winter types on the whole the more vigorous still. The contrast between March and

April may therefore be mentioned in order to explain the modification in the weather now setting in. The most prominent feature, on the whole, is the drifting of the Rocky Mountain high pressure to the northeastward, nearly into the Lake region, and the supplying its place by the more permanent low which enters that region from the southwest, intruding northward from the Gulf of California. The result of this change is to transfer the discharge of the cold air from the interior of the continent, where it still lingers near Hudson Bay, from the western to the eastern side of the Lakes. Hence sudden outflows of cold winds occasionally advance over the Middle States and New England, by which one is reminded that winter has not yet gone from those districts. Usually there are few well-defined symptoms of these invisible highs beyond the existence of two lows, one near New England and the other to the west of the Lakes. In such cases it is generally the effect of a cold area of high pressure developing to the northward of the limits of the territory represented by the weather map, and colder weather may be forecasted from the lower lakes to the Middle Atlantic and New England coasts.

In contrast with these cold northwest winds of the east, it is found that strong warm winds prevail in the southern and Rocky Mountain districts. They are often of great velocity and carry immense quantities of sand and dust over the plains to the northward. These may be called "southers," in distinction from "northers" of winter, which prevail in Texas and Arkansas, being the flow of very cold air southward along the mountain slope as a high advances to the southeast. An attendant feature of the south wind is to carry the isotherms rapidly to the northeast, from Texas to the Lakes, causing hot weather in the Mississippi and Missouri valleys, often in unseasonable severity. This process may go so far as to make conditions for severe local storms, thunderstorms, and tornadoes in Missouri, Iowa, Illinois, and would no doubt do so more frequently if the air were sufficiently charged with moisture, which does not always happen at this time in the spring.

At any rate, such a marked interchange of cold and warm winds in the central valleys is an important part of the April weather, and it is attended by rapid and wide oscillations of the barometer in these regions. There frequently occur great depressions of the barometer over the entire mountain plateau and slope, sometimes with high wind velocities, sometimes without them, even though steep gradients exist, in which there may be but little precipitation. This is probably due to the fact that in the increase of the general heat of the atmosphere in the middle latitudes the capacity of the air for greater quantities of moisture is increased, while there is also a corresponding diminution in the size of the cold masses that may be projected into the warm masses in order to produce a fall of rain. Hence, strong gradients and wind do not necessarily imply much rain, and such storms may move to the Atlantic coast and go over, as it were, very dry, with only

an occasional shower. The showers of April may be simply understood: Instead of the atmosphere being collected into great sheets of cold and warm air, which, as in winter, move eastward over the United States in a succession of waves, the cold and the warm masses become broken up into smaller portions or patches, which lie interspersed among each other in an irregular way. The contact of such masses of air in smaller bodies tends to cause local showers, and this condition lasts for a month or two, till the entire northern cap becomes warmed up, when summer conditions become fully established.

It may be not uninteresting to note the three ways that exist in the atmosphere of condensing moisture suspended in the form of aqueous vapor into rain. The first is the adiabatic cooling, which consists in the cooling of the air by expansion when it rises from the lower to the higher strata, by which the cumulo-nimbus and nimbus clouds of summer are chiefly produced, from whose bases the rain falls. The second is the intimate mixture of two masses of air having different quantities of vapor in them, but it has been shown that only small amounts of rain can in this way be produced, although very extensive fogs may be formed. The third is by far the most important, and, although in some respects a complex process, it may be called direct cooling by contact. One of the most important physical properties of air at different temperatures is a reluctance to mingle. Such masses will rather flow alongside each other in distinct strata, like oil and water, with contact on the surface. The effect of this is seen in many of the cloud forms that spread over the sky, showing exactly where the currents of different temperature touch each other. In the cyclonic circulation of the atmosphere, which is to be referred primarily to the counterflow of currents from two adjacent high areas, there is a powerful force that produces a breaking up of the currents into shreds of air, warm and cold in quick alternation, in the interflow especially in the south-eastern quadrants of the lows. Here the direct contact in the air of masses having moisture in suspension with the cold masses that are partially dry tends to form rapid condensation and hence rainfall. The operation of such a principle extending to the minute portions of the air will cause the fall of the moisture as rain, and thus dry the air thoroughly. Since the low is sustained between two highs and drifts eastward with them, this process of direct cooling between minute masses of air is going on continuously in the eastern quadrants of a storm where the rain falls, and the passage of the low is followed by clearing and cool weather in the current from the northwest that has not yet been able to reach any moisture-laden air. No doubt all these three processes are at work more or less simultaneously, but it is clear that direct cooling is the most efficient of all in producing ordinary rainfall in middle latitudes.

An examination of the storms and tracks for the years 1884-1893 shows that 24 originated in the Alberta district, 23 on the North Pacific

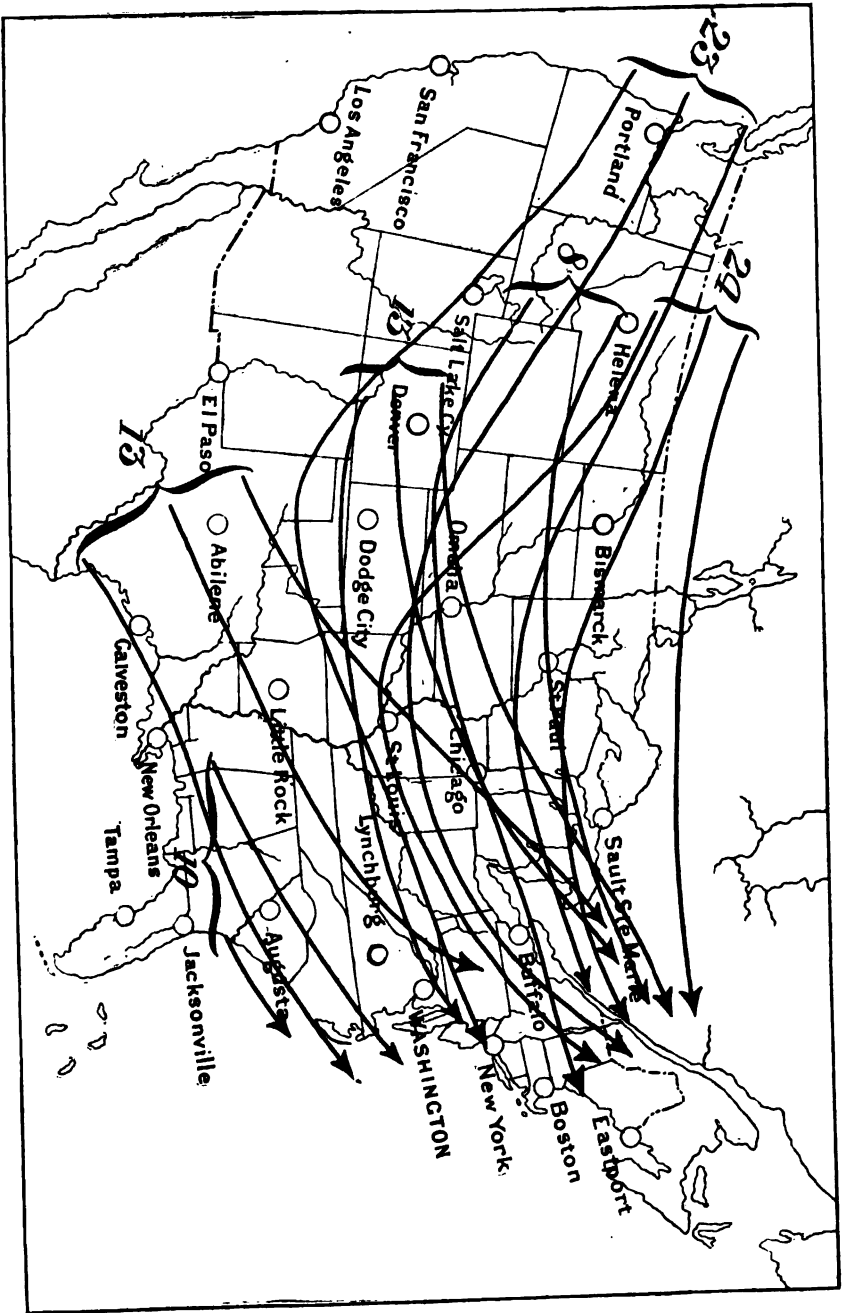


Chart 13.—Storm tracks for April.

coast, 8 on the northern Rocky Mountain plateau, 13 in Colorado, 13 in Texas, 10 in the east Gulf or south Atlantic States, a total of 91, 9 per year, or 1 every three and one-third days. The Alberta type shows a decided eastward movement in the northern circuit, with a moderate looping in the case of a few storms into the Ohio Valley, before reaching the Gulf of St. Lawrence. A high area usually occupies the central valleys when this type of storm forms, and as the high drifts northeastward the low follows behind it. The movement is somewhat slower than in March, and by the end of the month at least one day more is required to make the eastward march. The North Pacific coast type is characterized by a decided southern looping over the mountain slope to Kansas or Missouri before recurving to the northeastward over the Ohio Valley and Lake region. In this case a very large high covers the mountain slope and the central valleys, and there is a possibility of the high moving in either one of two paths, which is quite different from the case of the Alberta type. Either the high may move directly northeast to the Gulf of St. Lawrence or else it may move southeastward to the Florida peninsula. In the former case the eastward drift of the upper strata of air seems to be more influential, and in the latter it is the tendency of the air to settle in the high-pressure belt of the Tropics over the South Atlantic coast that appears to have dominated. In the first instance the low may move much more directly eastward from the Pacific coast, and in the second it advances far southward and then recurves along the northern border of the high as it continues to discharge through the low. This type of low in April takes about five days to reach the Gulf of St. Lawrence; in case the storm moves to the Lower Mississippi Valley, it may dissipate near the Gulf of Mexico on about the fourth day. The Colorado type shows little tendency to settle farther southward, but these storms advance directly northeast in rather a wide track, either to the middle Atlantic coast or to the lower Lake region, over the Ohio Valley. In this case, also, the high shows the same uncertain impulse to move either northward or southward along the Atlantic coast, as in the Pacific coast type. These storms also move slowly, and in many instances they take five days to reach the Gulf of St. Lawrence. A few of them likewise dissipate near the mouth of the Mississippi River.

The Texas type may perhaps be subdivided into two groups of storms, those originating in western Texas and moving northeastward on the inside track west of the Alleghany Mountains, and those which form near the west Gulf coast and move eastward to the coast on the outside track east of the mountains or along the coast line. These storms generally form with a high in the Lake region, or to the northeastward, and they usually advance rapidly to the Gulf of St. Lawrence, reaching that region in about three days. The South Atlantic type occurs with a high on the Rocky Mountain slope, heaviest in the southwestern districts, and the storm advances rapidly along the coast line to the north. It also happens sometimes that another low of the Alberta type is advancing

eastward, and the conditions are then favorable for diverting this low from the St. Lawrence Valley track southward over the Middle States to New England. Thus these two independent storms may unite in the neighborhood of New York City, and in that event severe winds and rain may develop on the North Atlantic coast. Sometimes such a storm instead of moving off to sea holds nearly the same position for several days, with a cold northeast wind and rain that causes very disagreeable weather in the New England States. In all cases the variation of rapidity of the eastward movement is the chief source of the perplexity in forecasting. It may be laid down as a rule that no inference can be drawn from the previous cases regarding the storm under consideration. It must be treated on its own merits, from a knowledge of the total conditions then existing.

One of the important duties of the Weather Bureau is to furnish warnings of frost and other conditions injurious to growing crops, and as the frost line moves south in the autumn and north in the spring over the United States, great care has to be exercised with these warnings, in the autumn for harvesting and in the spring for protecting the young plants. Therefore, the following districts are attended to in the course of the year: The tropical fruit districts, the sugar and sorghum districts, the cotton region, the rice districts, the vegetable and fruit districts, the stock-raising districts, the cranberry districts, and the tobacco districts. For cranberries the forecasts are made from May 1 to November 1; for sugar, from October 1 to April 1; for tobacco, from September 1 to November 1; for fruit and vegetables, from September 1 to June 1; for cotton, until the cotton is gathered or freezing weather occurs. The time for which the frost warning is sent to the different States is approximately as follows: All the year to east Florida, west Florida, southern Mississippi, southern Louisiana, and southern Texas; after February 15 the frost warning line is through the central part of South Carolina, Alabama, Mississippi, Texas, and all of Louisiana; after March 1 it includes North Carolina, Kentucky, Tennessee, southern Indiana, southern Illinois, Missouri, and Arkansas; after April 1 it is as far north as New York, lower Michigan, Wisconsin, Minnesota, and South Dakota. In the autumn the line advances southward in almost similar proportions. Frosts and freezing weather can usually be predicted twenty-four hours in advance, and in spite of the fact that failures sometimes happen, generally in the nonoccurrence of frosts expected, there is no doubt that all farmers who follow the warnings of the Weather Bureau carefully and protect their plants will save more than their neighbors who do not use the forecasts.

MAY.

STORM TRACKS.

A description of the weather conditions for May must necessarily resemble closely that already given for April. The transition from winter to summer is, however, much advanced, and the frost line disappears

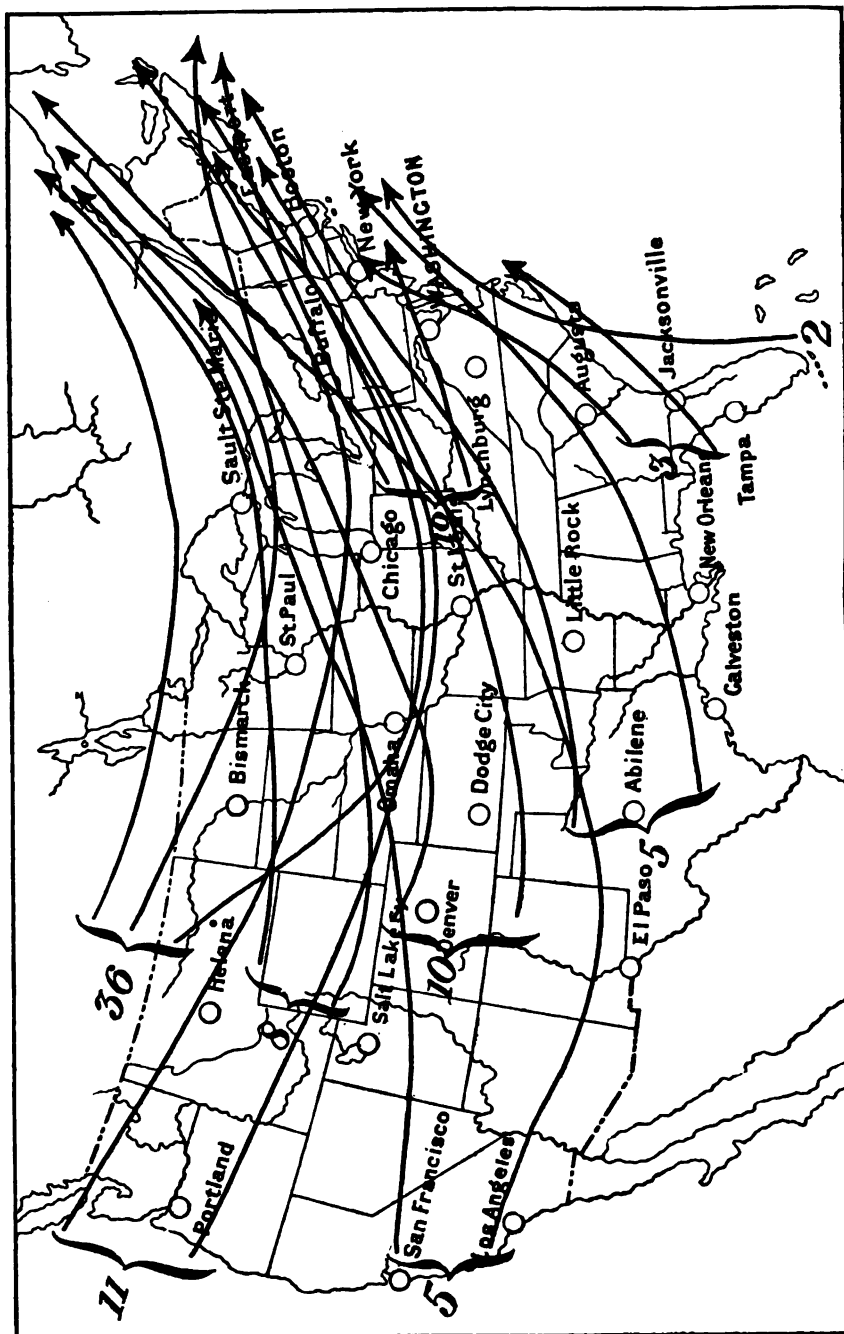


Chart 14.—Storm tracks for May.

from the Northern States about the end of the month. The tendency to form low areas in the Rocky Mountain region, sometimes quite free from precipitation, is increased, the sporadic character of the rains is pronounced, the eastward drift is much slower, the storm tracks seek more closely the northern circuit, and generally a flatter system of weather types prevails. A count of the number of storm tracks in May for the years 1884 to 1893, inclusive, shows that 36 originated in the Alberta district, 11 on the North Pacific coast, 8 on the northern Rocky Mountain plateau, 10 in Colorado, 5 in Texas, 3 in the east Gulf States, 10 in the central valleys, 5 on the South Pacific coast, and 2 in the West Indies. The tracks pursue the same general course to the Gulf of St. Lawrence, only with much less looping southward on the Rocky Mountain slope.

JUNE.

LOCAL WEATHER CONDITIONS.

The entire weather system of the United States has fallen in intensity by the month of June to the flat and stagnant state that characterizes the summer months. In accordance with the prevailing continental conditions, the interior is overheated relatively to the coast districts, and therefore low areas prevail in the central valleys, especially in the Rocky Mountain slope, while the highs tend to dominate the coast districts. The violent expulsion of high areas of cold, dry air from the interior to the coast in the northern and the southern circuits has subsided into the occasional highs that drift slowly across the country, bringing showers and cool weather with them. The heavy, overcast skies of April and May, with rainy weather, have changed into local showers, thunderstorms, and tornadoes, all the products of a vertical rather than a horizontal circulation of air. In the winter and spring the precipitation is confined closely to the periphery of the highs, but in the summer the showers are very likely to occur within the high areas as well.

The storm tracks are now much more simple, being confined to the northern circuit and the feeders that come from the south and southwest. The looping downward to the south along the mountain slope has almost ceased to be important. Many storm tracks, instead of persisting to the Gulf of St. Lawrence, die out in the middle districts and curl about in an erratic, feeble manner. A count of the storms in ten years shows that 24 began in Alberta and the Saskatchewan Valley, 7 on the North Pacific coast, 20 on the northern Rocky Mountain plateau, 14 in Colorado, 4 in Texas, 4 in the east Gulf States or near the South Atlantic coast, 3 in the central valleys, and 4 on the South Pacific coast. The great majority begin on the eastern edge of the Rocky Mountains, showing that this elevated range has much to do with throwing the eastward drift of the upper current into these cyclonic whirls.

The tornadoes of June occur chiefly in the Mississippi and lower

Missouri valleys, where the humidity is high, the temperature excessive, and the conditions for local vertical circulation greatly increased. Thunderstorms are spread over the mountain slope, but especially in the Mississippi and Ohio valleys, and the northeastern districts. This indicates that the colder air derived from the northern circulation has much to do with this form of precipitation and sudden downflow of cold air from the upper strata of the air.

JULY.

STORM TRACKS AND WEATHER CONDITIONS—FORMATION AND CHARACTERISTICS OF TORNADOES.

A count of the storms of July originating in the several districts of the United States shows that they reach their maximum number in Alberta, that is, in the midst of the great storm track, and that the rest are scattered about in a very irregular manner, indicating that there is no strong prevailing impulse to control their formation. Thus we find in a ten-year period 41 in Alberta, 4 on the northern Rocky Mountain plateau, 8 in Colorado, 1 on the North Pacific coast, 6 on the South Pacific coast, 2 in the South Atlantic and East Gulf States, 3 in the West Indies, and 17 in the central valleys and the Lake regions.

Only a few storms survive long enough to pass across the United States. Those originating on the Pacific coast are likely to dissipate in the central valleys, and some forming east of the mountains on the slope are liable to disappear near the Lakes; those, however, which commence in the central valleys will probably reach the North Atlantic coast or the Gulf of St. Lawrence. All these features point to local and minor weather features, which indeed characterize the month of July, being in the midst of summer.

At this time, when the warm weather is at its maximum, the continental conditions are most fully developed. The interior of the country is heated, the ocean districts are comparatively cool. The great Atlantic high area, produced by the general circulation, protrudes upon the southeastern districts; in the same way the Pacific high overlays the northwestern districts of the mountains. Hence, between these in the Mississippi and Missouri valleys, there is a region of encounter for the southern winds produced by the Atlantic high and for the northern winds maintained by the Pacific high. The southern winds are warm and charged with aqueous vapor; the northern winds are cool and comparatively dry. The meeting of these two types of winds in the central valleys, the same conditions also extending along the Ohio Valley to the lower Lakes, is attended by two or three typical local effects. In the first place, there are calms at intervals, local pools of stagnant atmosphere, into which these opposing currents have not penetrated; in the second place, the intense radiation of the sun superheats the strata of air near the ground and causes relatively unstable equilibrium, with its tendency to overturn the strata in a vertical direction;

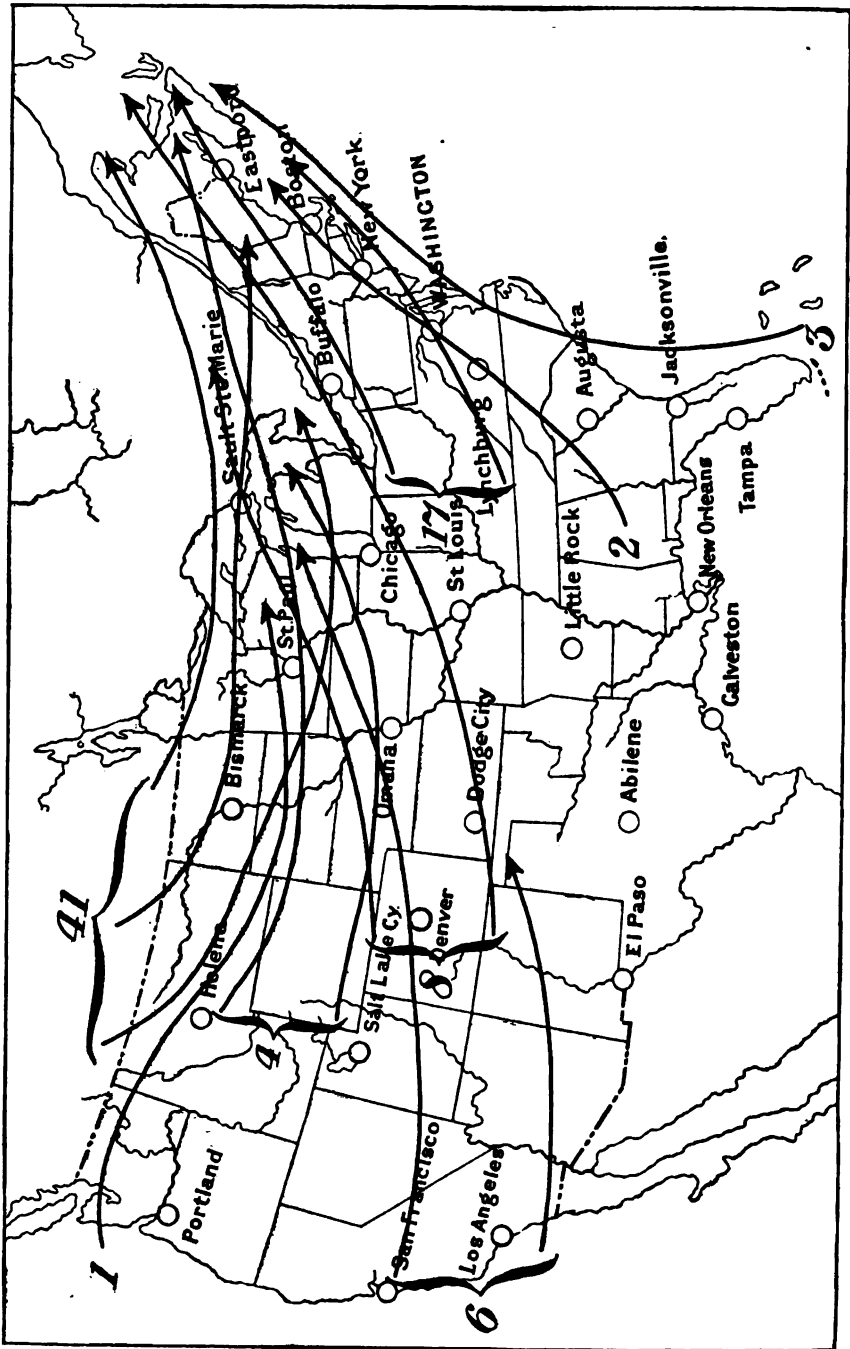


Chart 16.—Storm tracks for July.

in the third place, the cool currents from the north, borne aloft in the general eastward drift, tend at times to overlay this stagnant atmosphere in the ground stratum and to increase the unstable equilibrium.

These are the conditions that always favor the formation of local storms, tornadoes, thunderstorms, and showers, in which precipitation generally occurs during the summer. Masses of air of different temperatures in the great north and south currents may thus approach a stagnant and calm region, such as the later hours of the afternoon develop, the increase of cloudiness being merely a symptom of the existence of rising and cooling currents which portend a storm, and finally set the entire mass into a mixed congested circulation. The cold air comes down and the warm air rises, but they both resist mixing intimately. Rather they tend to be drawn out into long bands or ribbons before such mixing is accomplished, and these are the conditions for local showers. When the condensation is rapid in the strata a mile high, the formation of thunderstorms with electric discharges is accomplished. In certain peculiar formations of the circulation a tornado tube is projected downward. This is a simple vortex, and obeys the laws of the movements of fluids in gyratory circulation. If a mass of air 6,000 feet in diameter is rotating at a half mile level and it runs into a vortex so that the tube is 100 feet in diameter, and supposing the outer edge of the upper vortex makes 7 miles an hour, then at the rim of the bottom of the vortex we should have a velocity of 200 miles an hour. This causes an enormous centrifugal force in the lower tube, a high vacuum, and low temperature. It is maintained only by a forward movement of the entire vortex system. The vacuum tube causes the explosive and disastrous effects upon objects in its path, as noted in the tornado incidents, the wind at great velocity prostrates every obstacle, the cold generates the sheath of vapor that makes the tube visible like a thin skin, the same sudden condensation causes electric discharges, just as in thunderstorms on a large scale. There is no real mystery about the formation of tornadoes or respecting their terribly destructive power. It all goes back to the same principle that discharges a gun, in which case there is a sudden formation and expansion of gas; but in the tornado it is the reverse process, namely the sudden production of a vacuum into which outside air discharges itself, that is, into the hollow vortex tube, and with the other result of quickly cooling the heated air drawn into the tornado vortex.

There is no available way of avoiding the occurrence of tornadoes in the weather conditions favorable for them. The tubes resist an explosive discharge in the air outside it, these having often been fired upon by cannon at sea. They sweep through a forest as readily as through a city. There seems to be no increase in the annual number of them. Some have sought to connect their recurrence with the sun spot frequencies, and it is possible that there is some indirect connection, just as in all the other weather elements, but only through the

features of the general weather circulation. If this is stagnant over large regions, then the tornado conditions will most readily develop. At present they can only be roughly forecasted as "conditions favorable for local storms." It may result from a better knowledge of the relations of local conditions to general circulation that improved forecasts may yet become possible, but this can be the product only of very extensive research and investigation.

The excessively hot spells of weather that cover the Atlantic States during certain intervals are attended by a high area on the South Atlantic coast, being a portion of the great subtropical high. Aside from the transportation of warm air from southern to northern latitudes, there must be a downpouring of dry, hot air in the high itself, due to the excessive "potential" temperature of the upper strata. How these layers become overheated is a question to be solved by a study of the general circulation of the air.

A summary of the number of storms developing in the several regions, marked off by the natural physical features of the United States as recorded in this bulletin is appended, and a glance at it will enable one to recall many of the statements that have been introduced regarding the weather of the several months.

Summary of the local origin of storms by districts for the ten years 1884-1893.

No.	Names of the geographical groups.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual group sums.
1	South Pacific coast	2	2	.....	.....	5	4	6	.....	.....	3	1	.....	23
2	North Pacific coast	20	18	28	23	11	7	1	.....	13	18	17	28	184
3	Alberta.....	32	27	39	24	36	24	41	45	39	36	35	49	427
4	North Rocky Mountain plateau	8	8	8	8	8	20	4	4	5	12	4	10	99
5	Colorado.....	10	13	12	13	10	14	8	8	7	11	5	14	125
6	Texas.....	21	18	14	13	5	4	.....	2	8	4	12	8	109
7	East Gulf and South Atlantic..	2	6	6	10	3	4	2	4	4	9	11	8	69
8	West Indian.....	.....	.....	.....	.....	2	.....	3	12	7	14	6	.....	44
9	Central	3	7	.....	.....	10	3	17	8	.....	3	12	.....	63
	Monthly sums	98	99	107	91	90	80	82	83	83	110	103	117	1,143

WEATHER CONDITIONS AT WASHINGTON, D. C., FOR THE TWENTY-SIX YEARS 1871-1896.

It is important to compare the relations of the meteorological elements at each station, as these vary in the seasons and from year to year. A condensed statement for Washington, D. C., covering the period 1871-1896 is given as an illustration of the kind of extremes and differences that may be expected at this place.

Statement of averages, etc., at Washington, D. C., for the twenty-six years 1871-1896.

Weather conditions.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Temperature:												
Mean or normal	33	36	41	53	64	72	77	74	68	57	45	36
Warmest month—												
Year.....	1890	1890	1878	1878	1880	1874	1876	1872	1881	1881	1896	1889
Degrees	44	43	49	58	70	78	81	79	77	63	51	46
Coldest month—												
Year.....	1893	1885	1885	1874	1883	1878	1891	1874	1871	1876	1880	1876
Degrees	25	27	34	48	59	69	72	72	62	51	40	26
Highest—												
Degrees	76	78	83	93	96	102	103	101	104	92	80	73
Day	12	23	22	18	26	9	18	13	7	3	13	4
Year.....	1890	1874	1894	1896	1880	1874	1887	1881	1881	1879	1879	1893
Lowest—												
Degrees	-14	-2	4	22	34	46	53	49	38	26	12	-13
Day	1	5	4	19	1	1, 6	20, 22	24	26	31	22	31
Year.....	1881	1886	1873	1875	1876	1873 1894	1890	1890	1879	1893	1880	1880
Frost:												
Average date first killing frost (in autumn)—												
Day										22		
Average date last killing frost (in spring)—												
Day				14								
Precipitation:												
Average monthly	3.50	3.31	4.08	3.16	3.90	4.29	4.84	4.44	3.82	3.27	2.88	3.01
Average number days 0.01 inch or more	12	11	12	11	12	11	11	12	9	9	10	11
Greatest monthly—												
Year.....	1882	1884	1891	1889	1889	1883	1886	1875	1876	1885	1877	1878
Amount	7.09	6.84	8.84	9.13	10.69	8.55	10.63	12.93	10.81	8.69	7.18	4.94
Least monthly—												
Year.....	1872	1872	1894	1896	1875	1873	1872	1892	1884	1874	1890	1889
Amount	0.23	0.93	0.98	1.07	1.01	1.63	0.82	0.85	0.14	0.29	0.79	0.19
Greatest amount in twenty-four hours—												
Amount	2.28	2.29	2.79	3.21	3.50	4.16	5.80	2.84	5.66	3.98	2.83	2.70
Day	4	5-6	9	26	7-8	22	29-30	29	15-16	4	24	17
Year.....	1886	1896	1881	1889	1886	1886	1878	1875	1874	1877	1877	1888
Greatest amount snowfall in twenty-four hours—												
Amount	5.0	10.0	6.0	4.0						(a)	2.5	10.0
Day	12	8	11	6						23	5	26
Year.....	1893	1886	1888	1889						1889	1891	1890
Weather:												
Average number of days—												
Clear	7	7	8	9	10	9	10	10	11	12	9	9
Partly cloudy	12	11	12	12	12	15	14	13	11	11	12	12
Cloudy	12	10	11	9	9	6	7	8	8	8	9	10
Wind:												
Prevailing	NW.	NW.	NW.	NW.	S.	S.	S.	S.	S.	S.	NW.	NW.
Highest velocity—												
Miles	46	60	48	43	54	48	60	53	66	51	54	49
From	NW.	NW.	NW.	NW.	SW.	S.	NW.	N.	SE.	NW.	NW.	W.
Day	30	2	24	8	28	26	4, 28	5	29	4	23	9
Year.....	1894	1876	1878	1879	1896	1877	1874 1877	1878	1896	1877	1891	1876

a Trace.

CIRCULATION OF THE ATMOSPHERE IN THE UPPER LEVELS—THE INTERNATIONAL CLOUD OBSERVATIONS.

In these papers much has been written about the cyclonic circulation at the surface of the ground, but the subject would be very incomplete without alluding to the efforts that are being made to determine the circulation of the upper atmosphere all over the globe. Theoretical solutions, to some extent confirmed by observations, have been given, and yet the true connection between the general and the

cyclonic circulation has not been properly cleared up and tested by experience. So far as the general movements are concerned, the components are somewhat as follows in the northern hemisphere, those south of the equator being counterparts; along the meridian from latitude 24° to the equator the component is south, to the pole it is north; in middle latitudes, where the extra tropical cyclones prevail, there is a southern component in the middle cloud strata, and two northern components, one near the ground and one in the cirrus strata. Along the parallels of latitude there are two systems of components; from 0° to 35° latitude a westerly component at the surface, and an easterly in the higher layers; from 35° to 90° latitude two easterly components, making a maximum and rapid eastward drift in the neighborhood of 54° . In the vertical, from 0° to 20° and from 70° to 90° latitude, there is an upward component; from 20° to 70° latitude a downward component. The cyclonic and the anticyclonic motions to some extent spring out of these, but the really active part of them is confined to the strata within 2 miles of the ground, and yet the precise course of the stream lines is not comprehended throughout their extent.

Much light has been thrown upon the obscure features of these problems by observation at high altitudes, and especially by measurements of cloud heights and velocities, but still much remains to be done to reach satisfactory conclusions. It is thought that some account of these international cloud observations, and a reference to the important literature regarding them, may be of interest to those who have these subjects at heart, especially those who are cooperating in the work of the Weather Bureau.

The attention of meteorologists in the early developments of the subject were naturally almost exclusively confined to studies on the data furnished by the lowest stratum of the atmosphere. The circulation and physical conditions of the air in the higher strata were investigated to some extent by means of the theoretical considerations and the general movements of clouds. It has, however, become apparent that a scientific knowledge of the action of the currents in cyclones and anticyclones can be obtained only by a determined attack upon the physics of the upper levels of the atmosphere. Progress in meteorology, working along the original lines at the surface of the ground, has for a number of years been disappointing, and it is well known that in the art of forecasting almost exactly the same methods that were perfected twenty years ago are still employed. There seems to be little hope of improving this state of affairs unless a radically new way of dealing with the data can be devised which will efficiently supplement the system now in use.

The Chief of the Weather Bureau has expressed the opinion that there are two or three lines of investigation promising the wished-for results. One is the practical development of knowledge regarding the polar magnetic energy from the sun. The serious difficulty in the way of doing this has been the expensive and complicated nature of

first-class magnetic observatories, which must necessarily limit the number in the United States. What we need is a simple, inexpensive, and yet reliable instrument that can be utilized as readily as a barometer, thermometer, or a watch. It seems now, after a couple of years of trial, that such an apparatus is in hand, and a record of its performance was published, with a description of it, beginning in the January number of the *Weather Review* for 1896.

Another process for getting at the action of the upper air is the transportation of barometers, thermometers, and other apparatus into the higher levels. This can evidently be done by mountain stations, balloons, and kites, and experiments are being conducted by the Weather Bureau to carry out this purpose as far as practicable.

A third line of investigation is the study of the clouds in all their aspects; the conditions under which the several forms are developed; the heights of the several levels, the variations of the same in the diurnal and annual periods, and particularly in connection with the cyclonic circulation of the lower strata; the direction and velocity of movement in the general circulation of the currents of the atmosphere as well as around the barometric maxima and minima. The fact that clouds are present almost every day in a series of forms which pass from one to the other by delicate gradations, each of which must indicate specific physical properties, shows that this is a very rich field of research which has been only imperfectly cultivated. Many interesting conclusions have been developed by observers of such phenomena in the past fifteen years, but only during the last five years has the conviction become general that this is one of the most important studies for the practical meteorologist.

With the view of reducing the details to uniformity of method and to secure cooperation among the observers in different countries, an organization has been completed which went into effect last spring. A brief history of the movement is as follows: The measurement of cloud heights is an old problem, and many devices have been invented for the solution of the practical difficulties, of which a full account may be found in the Report of the Chief Signal Officer, part 2, 1887, by Prof. Cleveland Abbe. More or less systematic observations, extending over considerable periods of time, have been made at Berlin, Upsala, Storlien, Kew, and Blue Hill (Mass.), by methods depending upon triangulation. Besides the simple trigonometric formulæ, another system for computing the shortest distance between the two sight lines, devised by Ekholm and Hagström, Upsala, also a process for reducing the points on a photograph plate exposed in a photogrammeter by Åkerblom, Upsala, have been successfully used and are recommended as the best known.

The following are the leading papers on cloud observations:

1. *Mesures des hauteurs et des mouvements des nuages*, par N. Ekholm et K. L. Hagström, Upsala, 1884.

2. Des Principales méthodes employées pour observer et mesurer les nuages, par Hildebrandsson et Hagström, Upsala, 1893.

3. De l'emploi des photogrammètres pour mesurer la hauteur des nuages, par Åkerblom, Upsala, 1894.

4. Observations made at the Blue Hill Meteorological Observatory, *Annals Harvard College*, Vol. XXX, Part III, by H. H. Clayton and P. S. Fergusson, 1892.

At the international conference, Munich, 1891, a committee was appointed to consider the question of concerted observations on the direction of motion and the height of clouds. This committee recommended that observations on the direction of motion and the height of clouds should be commenced at certain stations distributed over the globe, and continued for one year; that short instructions be prepared for these observations; that the scheme of cloud classification put forth by MM. Hildebrandsson and Abercromby be adopted, and a cloud atlas illustrative thereof be published.

As the result of these propositions, the cooperative international cloud observations began May 1, 1896, and will continue one year. As far as known, the theodolite method will be employed at Washington, D. C., Blue Hill, Mass., and Christiania; the photogrammeter method at Upsala, Paris, Potsdam, St. Petersburg, Nijni Novgorod, Manila, Batavia, Melbourne, and probably Kew, Calcutta, and Sydney. The difficulty in cloud observations is to have two observers, separated by a base line nearly 1 mile long, set their sight lines on exactly the same point of a rapidly moving and dissolving cloud. The advantages of the theodolites is that the instruments are cheaper, many more observations can be taken with the same labor, and the calculations are the briefest possible by any method. The observations that must be rejected at the outset can be determined by a small platting machine, being a model of the real base line and instruments, such as the one invented by H. H. Clayton, at Blue Hill. Photographs, on the other hand, possess the advantages of giving definitely the point on the cloud, but the difficulty of securing photographs of all kinds of clouds in all weather is very great and the cost of the work much more for the same number of individual observations. The international classification of cloud forms being issued, it was adopted by the Weather Bureau. It went into operation July 1, 1896, throughout the service, and suitable instructions and illustrative forms were prepared for the observers. The atlas of cloud forms issued by the international conference committee is now ready for distribution, and may be purchased of M. Teisserence de Bort, Bureau Central Météorologique, 176 rue de l'Université, Paris, France.

Besides the observations with theodolites and photogrammeters for the actual heights and velocity of motion of clouds at the primary stations, a number of secondary stations for the relative motions and the other available data will be established in each country. In the United States there will be twelve such stations under the immediate control of the Weather Bureau, equipped with nephoscopes for the observations. It is very desirable that the network of the stations be made as complete as possible in all parts of the country, and it is hoped that

this opportunity for cooperation may be embraced by other persons willing to do some valuable scientific work. The colleges might profitably instruct their students in such observations at a very moderate expense. A first-class nephoscope can be made for \$20, and serviceable ones at lower rates. The observations would require half an hour's work three times a day, between 8 and 9 a. m., 1 and 2 p. m., and 5 and 6 p. m. The Weather Bureau will furnish suitable instructions to observers, and will aid them as far as possible in explaining the very simple computations that would be needed to prepare the observations for final discussion.

There are many forms of nephoscopes in use, but the one devised by Professor Marvin, of the Weather Bureau, seems to be especially well adapted to the requirements. A description of it appeared in the January, 1896, number of the *Weather Review*. It may be said in this place that its best feature is the device for keeping the sighting knob exactly 12 centimeters above the mirror in every possible position, so that the unit of height becomes 1,000 meters, and the velocity in meters per second at that height is just one-third the number of millimeters passed over by the image in 25 seconds. This makes the computations very easy, and when the height of the cloud level is known from the theodolite work the actual velocity is obtained by simply identifying the cloud observed from its form as belonging to such a level. The mean of a large number of observations gives a true velocity. The base line at Washington is about 1,360 meters long, one end on the Weather Bureau building and the other on the War, State and Navy building. The ratios of velocity by the theodolites and nephoscopes at this station in the different cloud levels give the means of using other nephoscope observations, provided the naming of the cloud forms is carefully done.

The ultimate problem is to obtain the coordinate velocities of the several components in the general circulation and the relation that these have to the cyclonic circulations which depend upon them. The importance of these solutions to the art of forecasting, and the fact that voluntary observations made in widely separated parts of the United States are needed as contributions to the network, together with the simplicity that pertains to nephoscope work, induces the hope that some interested in the physics of the air may take up the task of cooperation.

**DESCRIPTION OF THE SOLAR MAGNETIC PERIOD OF 26.68 DAYS
AND ITS RELATION TO THE FORMATION OF STORMS IN THE
NORTHWEST—DEFINITIONS OF THE TERRESTRIAL MAGNETIC
ELEMENTS—SOLAR MAGNETISM AND ITS CONNECTION WITH
THE WEATHER.**

A careful study of the succession of the highs and lows in the northwest has revealed the fact that there is a peculiar curve which they try to follow in their intensity, and that they tend to repeat the same curve every 26.68 days. This curve has a grand sweep with two maxima

and two minima in it, and ten minor crests spread along it in quite a symmetrical manner. The next striking peculiarity of the eastward drift is that the succession of the highs and lows is along this curve in one position, and then along the same curve when it is inverted or turned over. This inversion is found to occur at uncertain intervals, and yet in such a way as to be certainly connected with the motion of the earth about the sun.

These considerations point to some kind of energy that comes from outside the earth, falls upon the whole hemisphere, and is associated with the sun's action. Finally, when the great preponderance in the number of storms in North America over the corresponding localities in Asia in the middle of the continent is considered—the number in America being about ten times as great as in Asia—it is necessary to look for some cause that accounts for this difference. The preponderance of storms in North America, the inversion of the order of their production, the alternate hastening and slowing up of the eastward drift, are facts of profound meaning in seeking the fundamental laws regarding the origin of storms.

A study of the variations of the magnetic field of the earth has brought out a new series of facts that seem to be very closely connected with those just mentioned. It is shown that a field of force is impressed upon the earth in directions that nearly coincide with the magnetic meridians. When this force increases, an impulse is propagated from the north to the south, and in case of unusual disturbance the magnetic and electric field of the earth suffers perturbations or storms that show themselves in an outburst of beautiful auroral light or in the electric earth currents that temporarily impede telegraphic communication.

An examination of the places of the relative frequency of the auroras shows that there is a maximum belt running from Alaska over the southern portion of the Canadian possessions, near the lower end of Hudson Bay, over Labrador, thence to the north of Norway, Sweden, Siberia, till the circuit is completed. In shape it is a rude oval, embracing the geographical pole and the magnetic pole, which is located near Boothia Island. The center of the outspreading magnetic force just mentioned is midway between these poles, and its meridians are perpendicular to the auroral ovals all over the hemisphere.

This force is at a maximum over the auroral belt, sinks away somewhat to the north, and falls rapidly to the south. Now it is known that the aurora, this magnetic force, and the sun spots all rise and fall together in intensity in the eleven-year period. This is another clew to our supposition that storm action is dependent upon the solar output, transmitted in long, wide sweeping magnetic curves, and falling upon the polar regions of the earth, the sunlight meanwhile radiating to its tropical zone.

Another group of facts of more detailed nature indicate the same conclusion. A study of the curves of change in the 26.68-day periods

show that the same variations can be traced throughout the magnetic fields of Europe, Asia, America, and Australia, the impulses being common to the earth. It is found that the temperature and pressures of the northwest have the same pulsation, which arrives in the Dakotas in one day after the magnetic change has taken place. This same curve, on applying the period through a long series of years, is discovered to be the type in which the sun spots tend to group themselves, the southern hemisphere being the direct type and the northern hemisphere the inverse type. This implies that the period 26.68 is that of the rotation of the sun's nucleus, and it agrees very closely with the time computed for the visible surface at the equator from the motions of the sun spots.

The inferences follow that the sun is an immense magnetic sphere, like the earth, the north pole positive and the south pole negative; that it sends out great waves of force which reach the earth in the disturbances; that the field of the sun is maintained at different strengths in the several meridians, and that as it turns around on its axis this field at the earth makes corresponding impressions upon the earth's field. A magnetic curve is like a delicate spring, and those from the earth and sun touch and bend in response to each other in the most wonderful manner. Hence all these observations at the earth, pursued for fifty years by the magneticians, are measures of the solar energy, and will some time be so interpreted as to become of great use to the world.

There is still another system of correspondencies between the magnetic and the meteorological actions. On taking mean values for a long series of years in the European magnetic field and the Dakota pressures and temperatures it is seen that these rise and fall in a very peculiar curve, which is that of the sun-spot areas fundamentally, with a shorter period, one-fourth of eleven years, superposed upon it. The persistence in this synchronism is such as to exclude anything like an accidental relation, and this summary embraces seventeen years.

A close computation on the position of the storm tracks in the United States shows that they rise and fall in latitude in the same long curve; also the speed of the eastward advance, the rate of propagation, changes in the same proportion; the intensity of the storm action, the amplitude of the highs and lows, and hence of the barometer and thermometer readings, give the same relative curves.

In all cases we have the unequivocal testimony presented that an increase of this polar magnetic energy increases the pressure, diminishes the temperature, changes the order of the production of storms upon inversion, their intensity, their speed of eastward movement, the position of the tracks, and generally precedes all the principal conditions known to exist in the elements of the physics of the atmosphere.

The last point to answer, why the storms preponderate in North America in number rather than in Asia, is simply because the magnetic

pole happens to be on this side of the geographical pole, causing the concentration of energy to take place in the midst of the North American continent, but to the northward of Asia. This condition of affairs tends to build a high-pressure belt over western Canada, just along this auroral belt where the magnetic energy comes down, and the continual interchange of power shows itself by stripping off a rapid succession of storms to the northwest of the United States, while in Asia a great undisturbed high prevails in winter and an immense low in the summer.

The correlation of such a vast system of facts, unbroken by any known contradictory evidence, leads to the belief that the solar energy reaches the earth in two ways—one along the ecliptic and the other perpendicular to that plane. A very plausible theory of the glacial ice waves is that during long periods the sun's magnetic output was increased, and that in consequence, as shown above, the temperatures of the arctic regions were greatly lowered. Hence it may easily be perceived that this new discovery of the Weather Bureau opens up a fascinating field of study into the great laws of the solar system, and that it may well be called a new chapter in cosmical astronomy.

It is known that the usually accepted system of meteorology indicates that a low-pressure belt should prevail along the northern borders of the United States, but as matter of fact high areas frequently form in that region and drift eastward in the northern circuit. In order to explain these apparent anomalies, it is suggested by the facts herein mentioned that the cooling tendency in the atmosphere along the auroral belt just to the north of the northern circuit is in part due to the action of the polar magnetic energy falling on that region. This facilitates the descent of the air of the upper strata to the lower, thus accelerating the turning of the air moving northward in the upper strata into the returning current moving southward in the lower strata, as the general theory of circulation requires. The North American highs are made by the air turning in direction from north to south and descending to the surface of the earth.

The great importance of understanding the cause of the formation of the winter highs in the extreme northwest, and also those proceeding from the district to the south of Hudson Bay and advancing thence to New England, is apparent to every forecaster. Upon the energy and rate of movement of these northern highs the whole aspect of the forecasts depends.

The connection between the magnetic forces of the earth and the sun and the meteorological elements of the earth's atmosphere have been shown to be so intimate that it is desirable to have an understanding of the meaning of the leading words used in the science of terrestrial magnetism in order at least to follow the statements made in this subject. The nomenclature grew up in consideration of the behavior of a freely suspended magnet rather than with regard to the wider aspects

of science that have since been developed, and hence the choice of reference directions is limited to practical rather than to the best possible system. In the northern hemisphere a freely suspended needle dips with its north-seeking end beneath the horizon and inclines to the west of the geographical meridians, taken as a whole over Europe, where the science was first studied. This needle will hang tangent to the line of force determined by the earth as a magnet at the station considered, and there have consequently been employed two systems of coordinates to define the force of the magnetic field at the point of suspension.

(1) The first system of coordinates is—

F, the *intensity* of the magnetic force of the earth.

D, the *declination*, positive west from geographical north.

I, the *inclination*, positive below the horizon.

These give the exact direction and magnitude of the magnetic force.

(2) The secondary system of coordinates is—

H, the *horizontal component*, positive north along the magnetic meridian.

D, the *angular declination*, positive west.

V, the *vertical component*, positive downward.

These also determine the *vector*—that is, direction and magnitude—of the magnetic force.

If the earth's magnetic field were permanent, these values of F D I or H D V would be constant at every station on the globe. But they are all continually fluctuating in several periods—the diurnal, the solar, the annual, and the secular.

The *diurnal period*, twenty-four hours, is due to the rotation of the earth on its axis, changing the components of the earth's normal field in relation to the external magnetic lines of the force in the ether as induced by solar action.

The *solar period*, 26.68 days, is due to the rotation of the sun on its axis, carrying with it the *coronal* magnetic field, which it continuously sustains, with an intensity varying along the solar meridians, and also as a whole in the solar eleven-year period.

The *annual period*, 365.25 days, is due to the earth's motion about the sun in its orbit, which changes the aspect of the sun's magnetic system relatively to that of the earth, as the sun moves in declination with the seasons.

The *secular periods* are but little understood, but there are several of them: (1) The eleven-year period, due to the slow workings of magnetic masses within the solar nucleus; (2) the longer period of five hundred to one thousand years, differing in the several parts of the earth, and due to the slow redistribution of magnetism within the earth, and (3) the very long secular periods of the sun as a variable star by which the terrestrial system must be affected, just as it is in the shorter periods.

To study the causes that modify the earth's normal magnetic field in

these several periods it is necessary to disentangle the superposed forces from the normal field, in order to have the components of the *deflecting forces* at any time. The simplest way of doing this in practical work is to take the magnetic meridian at a station as the plane of reference with—

X, positive to the magnetic north.

Y, positive to the magnetic west.

Z, positive to the magnetic nadir.

Hence, *variations* in the horizontal force ΔH , in the declination ΔD , in the vertical force ΔV , may be combined into a horizontal component σ , which makes an angle β on the horizon plane with the magnetic north, and also into a total vector force s which makes a vertical angle α with σ , and an angle β between its plane and that of the magnetic meridian. In Chart 17

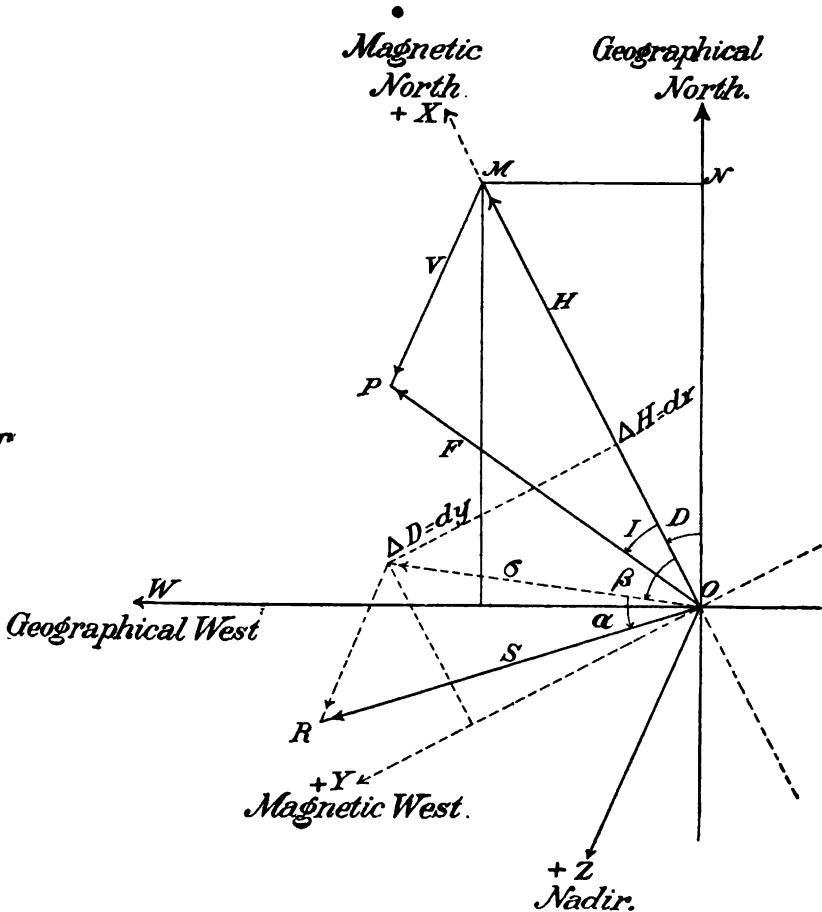


Chart 17.—Coordinates of normal and deflecting magnetic forces.

O N is geographical north, O W west, O Z nadir.

O P = F, N O M = D, M O P = I. First system.

$OM = H$, $NO M = D$, $MP = V$. Second system.

σ is the resultant of $\triangle H = dx$ and $\triangle D = dy$, and makes the angle $\beta = \angle H O \triangle D$ with the magnetic meridian.

s is the resultant of σ and $\triangle V = dz$ and makes the angle $\alpha = \angle D O R$ with σ . The vector sum of OP and OR is OT , and therefore OT gives the direction of the needle and the intensity of the magnetic force at the time considered.

For many years it has been known that there must be a close physical connection between the sun and the earth because of the definite fluctuations in intensity between solar and terrestrial phenomena. The investigation of this subject has shown that the transference of energy is not only along the ecliptic, but also in widespreading lines which are perpendicular to the ecliptic at the earth, this circumstance indicating that the sun, as well as the earth, is an immense spherical magnet. The sun therefore emits energy along two paths to the earth and in two different forms of radiation: (1) Along the ecliptic, in *electromagnetic waves*, wherein the vibration is in planes perpendicular to the line of propagation; (2) in *magnetic curves*, wherein the ether motion is probably rotatory, which is called the *coronal field* because of the intimate relation of the lines of the solar corona to magnetic lines of force.

When the coronal magnetic field approaches the earth perpendicular to the plane of the orbit, the lines of force are disturbed and their direction changed to enter the surface at such angles as correspond to the *permeability* and to the shape of the permeable mass. The result of the computation is that the earth acts like a permeable shell, such as soft iron which can be magnetized by induction, and the magnetic curves conform to a permeability 2, and to a depth of shell of 800 miles. Near the poles the curves are swept to the side, and concentrate in the auroral belt, or ovals, which surrounds the magnetic and the geographical poles; also other magnetic lines are crowded together in the Tropics. In the latitude of the United States the field is thinner and somewhat confused, owing to the interplay of the polar and the tropical fields. The entire field acts nearly along the magnetic meridians, except under disturbances and local distortions, but with an intensity which varies from day to day. It has been computed that there is a periodicity of 26.68 days in the coronal field, which gives a curve of relative intensity, as shown in Chart 18, for each revolution of the sun on its axis, and represents the average intensity of the solar magnetism from meridian to meridian. The curve is quite symmetrically balanced about two axes at right angles to each other, giving crests that correspond on either side in pairs. From this may be computed the primary form of the distribution of magnetism within the solar nucleus. The period is almost exactly that of the sun's visible surface at the equator, as determined by observations on the sun spots.

A very laborious discussion of this coronal magnetic field at the

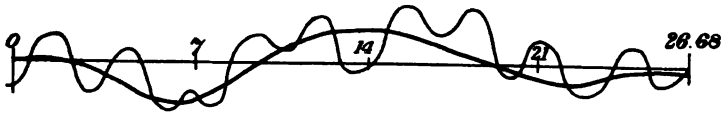


Fig. 1. Direct type of Solar Magnetic Field.

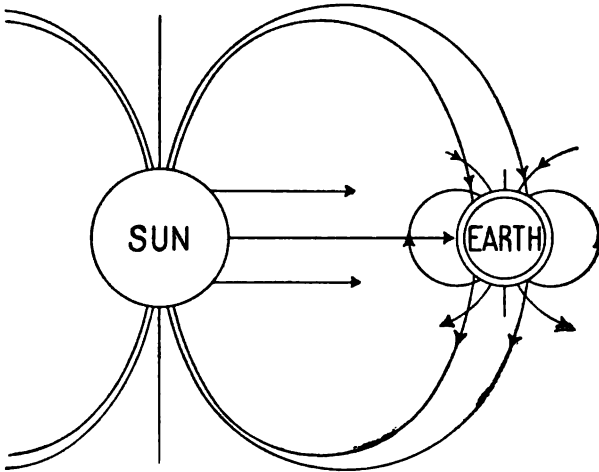


Fig. 2. The Sun's Coronal Magnetic Field.

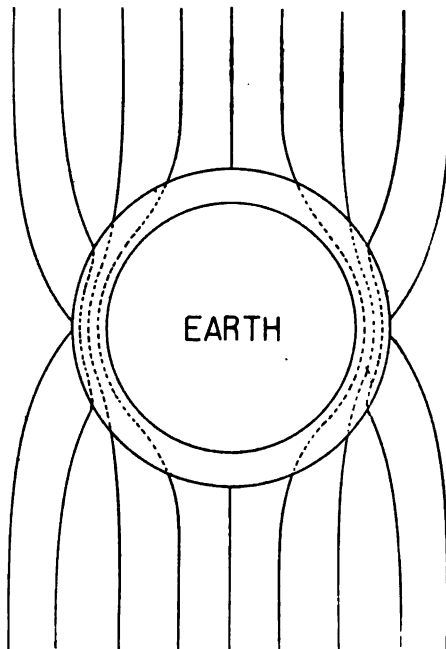


Fig. 3. The Earth a Magnetic Shell.

earth gives the important conclusion that the field is impressed in two types, that is, in the form shown in the diagram called the *direct type*, and also in the form that results from turning the curve over on its long axis, called the *inverse type*. Now the pressures and the temperatures of northwestern United States and Canada just east of the Rocky Mountains pass over a station on the average in such a way as to follow this peculiar curve, showing that the general circulation of the earth's atmosphere is to some extent controlled by this coronal impressed field which depends upon the rotation of the sun on its axis. The eastward drift, the alternate hastening and slowing up in middle latitudes, as shown by the rate of motion of the storms, are all features that apparently depend upon this polar field.

In order to account for this peculiar inversion it has been shown that the sun spots, arranged on meridians according to this period, reproduce the same curve, with the direct type in the southern hemisphere and the inverse in the northern hemisphere. The physics involved is complicated, but the inference is that the northern hemisphere of the sun is positively magnetic while the southern hemisphere is negative. The passage of the earth as a magnet about the sun involves it, in respect to the direction of the solar magnetic lines, within two systems of couples, which produce the effects observed at the surface. It has also been discovered that the law of inversion of these types involves a semiannual periodicity so disposed to the planes of the sun's and the earth's equators as to be dependent upon the earth's orbital motion with approach and recession of the magnetic poles twice each year. The vectors of magnetic force belonging to the electromagnetic or visible sunlight field have been worked out, and the results, transferred to a large globe, confirm the view that the earth acts like a spherical magnetic shell. These impressed forces explain the diurnal movements of the needle in all latitudes and are to be referred back to a complicated system of forces whose curves are distorted by the earth placed in a uniform field which is parallel to the ecliptic.

The entire subject is of great interest to the physicist and of much importance to the meteorologist. Some idea of the power of the coronal field over the atmosphere may be gained by reference to the results of a computation embracing observations of the northwest of the United States and of Europe for the years 1878-1894.

The following variations take place simultaneously:

In the maximum polar field (auroral belt), 0.000050 C. G. S.

In the European field (also United States), 0.000010 C. G. S.

In the external coronal field (near the earth), 0.000030 C. G. S.

To these correspond, when the above changes are maintained for a year, as is the case in the northwest of the United States and west Canada—

Change in the mean annual pressure, an increase, 0.02 inch.

Change in the mean annual temperature, a decrease, 2° F.

Change in the mean annual pressure amplitude, -0.01 inch.

Change in the mean annual temperature amplitude, -0.2° F.

During certain years in the Dakotas the pressure averages higher and the temperature lower; the average swing of the oscillations from high to low and from warm to cold, taken day by day, is less; and this takes place in years of increased magnetic force from the coronal field in the proportion given above.

In order to show how widely these changes occur from year to year, it is found in the sun spot cycle 1878-1890 that the following ranges took place in those districts:

Range in the European magnetic horizontal component σ , 0.000060 C. G. S.

Range in external solar coronal field, 0.000180 C. G. S.

Range in the maximum polar (auroral) field, 0.000300 C. G. S.

Range in the northwest (the Dakotas) pressures, 0.10 inch.

Range in the northwest temperatures, 7° F.

Range in the northwest pressure amplitudes, 0.06 inch.

Range in the northwest temperature amplitudes, 1° F.

Actual figures for the years 1878-1894.

Years.	European horizontal σ .	The Dakotas.		Amplitudes.	
		Pressures.	Temperatures.	Pressures.	Temperatures.
	C. G. S.	Inches.	Degrees F.	Inches.	Degrees F.
1878	0.000064	29.95	46	0.154	4.2
1879	.000071	29.98	44	.176	6.7
1880	.000084	29.98	43	.172	6.4
1881	.000087	30.04	39	.121	6.3
1882	.000108	30.05	37	.142	6.2
1883	.000099	30.07	38	.158	5.9
1884	.000098	30.04	37	.117	6.5
1885	.000094	30.06	37	.112	6.9
1886	.000088	30.02	41	.128	6.6
1887	.000071	30.03	36	.150	7.1
1888	.000073	30.06	37	.138	6.4
1889	.000068	30.04	42	.147	6.2
1890	.000050	30.04	40	.144	6.7
1891	.000083	30.03	38	.155	6.6
1892	.000101	30.05	39	.131	6.2
1893	.000096	30.00	41	.148	7.1
1894		30.03	42	.158	6.6

The connection between the magnetic forces and the pressures is much more clearly defined than with the temperatures, but the data should be plotted into curves and studied. The functions show that for an increase in the intensity of the solar magnetic force there results an increase in the pressures and a decrease in the temperatures, with a diminution in the pressure and temperature amplitudes. In other words, the years of greater magnetic intensity give higher pressure

over the Arctic region, colder weather, more steady conditions, that is, with less range in the climatic fluctuations. The pursuit of these studies into all regions of the earth will no doubt disclose some of the hidden forces that have made weather so difficult a subject to understand and to forecast its probable conditions.

GENERAL REMARKS ON FORECASTING.

PRACTICAL WEATHER FORECASTING.

This bulletin will evidently be more nearly complete if some statements regarding the practical art of making weather forecasts for the United States are added. The difficulty of doing this successfully is considerable because of the great complexity of the material and the large element that personal judgment must necessarily play in the interpretation of any given map of the weather conditions. Yet it is believed that certain principles can be laid down which should have much influence in the improvement of anyone desiring to learn forecasting, and in the correction of imperfect notions among those already somewhat practiced in this work. The author is alone responsible for the following remarks, inasmuch as they represent his own conclusions, drawn from the making of practical daily forecasts, rather than those of anyone else.

1. The leading point in making forecasts is to determine which are the primary and which are the secondary weather forces, that is to say, whether the highs or the lows are to be regarded as dominating in the mechanism of the atmosphere. We have been forced to abandon the earlier view that the lows or storms are most important, and conclude that in forecasting the highs are always primary and the lows secondary. Many reasons can be given for this change of view. The forceful character of intensely developed storms have so impressed the public, and many students as well, with their characteristic features as to have secured for them undue consideration in the interpretation of the maps. Stormy weather, precipitation, high winds, local storms, and thunderstorms have been so associated with the low pressure that many were persuaded that the lows were the primary and the highs only a secondary feature of the weather. A whole literature, based upon the convectional theory of storms, has thus subordinated the highs to the lows. But if the highs depend upon local overheated areas which overflow and form the highs, then whole features of the general circulation are ignored and the accompanying minor effects in storms are exaggerated into primary causes. On the other hand, as a matter of fact, complete lows are formed without temperature gradients of importance; they exist without precipitation; they do not frequent the Tropics, where heat and rain most favor their formation; their insignificant size precludes the idea that their products are seen in the adjacent highs.

Our view is that the lows are mere appendages to the high areas,

and these are built up in the general circulation which depends upon the temperature gradient between the equator and the poles, and thus have a sufficient and continuous source of supply for their large masses. The running down of the highs by gravitation causes gyratory lows to form along their periphery, as in tropical hurricanes, and especially between two adjacent highs where the countercurrents meet in the vortical trough or centralized storm, particularly in the middle latitudes. This is in harmony with the fact that the opposite sides of lows are of such different temperature, and that the precipitation is merely the waste product of the reduction of masses of air of different temperatures and vapor contents to the same physical state. The outcome of studies of cloud movements and the resulting knowledge of the general atmospheric currents lend great weight to this order of development. Such observations show that the upper strata are but slightly distorted from their average eastern drift except within about 2 miles of the ground. It is a principle of hydrodynamics that a fluid will not long move in a straight line, or even in an easy curve for a very long distance, without being thrown into a gyration upon encountering any obstacle, or at the least failure in the pressure gradients which are required for such movements. In the upper as in the lower atmosphere the temperature is constantly disturbing the normal north and south gradients, and the deflecting force of the rotating earth is prompt to take advantage of this variation. Hence the rapidly moving eastward upper strata are prone to swerve into a right-handed vortical movement in the northern middle latitudes, and then they burrow downward to the surface of the earth under the action of gravity, bringing cool, drying air in large masses of higher pressure, which necessarily flow out from the center of this circulation. The power behind the downward anticyclonic circulation of middle latitudes is the same as that which drives the trade winds, namely, the general tendency to equilibrium in the atmosphere. Its amount is measured by the difference in velocity of eastward movement in the upper and the lower strata. Without it the eastward drift would be very much more rapid than it now is. Such air must be disposed of and returned to the upper strata. The two adjacent highs throw out countercurrents which produce a vortex, to a large extent dynamic in its construction, that is to say, sustained by pressure transmitted hydrostatically from the high centers outward, and therefore *driven upward and compelled to rotate against the eastward-flowing strata into which it is injected*. The currents in the cumulus clouds strata show this, where the stream lines are soon wiped out at the distance of 2 miles or less above the ground, beyond which elevation the cyclone shows only a small distortion of the eastward streams. These lines of upward cyclonic discharge are perpetually renewed by the air driven outward from the highs, and they may therefore persist as long as the highs are maintained—that is, while the general circulation seeks a particular

local downward discharge. This may properly be called a *stationary circulation*, since a similar flow at the same relative point in the atmosphere will give the same pressure, although the entire system of high and low drifts eastward in the middle latitudes. This is a much better word to describe the case than the *stationary waves* of Von Helmholtz or Max Margules, since the analogy of a *stationary wave* is very unlike this process, a wave being formed by transmission of energy through the same mass of material, a *stationary circulation* by the transfer of different material through the same region in an equal flow. The air flowing from the northwest toward the equator and from the southwest toward the poles in middle latitudes does not move in great sheets, as the general theory of Ferrel or Overbeck implies, but in immense detached masses, and these are chiefly concerned in building first the highs, and out of them the lows. The details of this interesting circulation are yet to be fully determined, especially the part the different strata play in forming it. At present the evidence is that the strata within 2 miles of the ground have most to do with it, the upper strata merely feeding the highs and receiving the discharge of the lows, but very little air passing directly from the top of a low into the top of a high.

The practical consequences of this view in forecasting are very important. The action of the high becomes the leading feature in determining the future conditions of the weather, and the lows are mere incidental or secondary consequences, however important to the public these may become. Therefore the track of a cyclone is along the edge of the high, combining the eastward drift with the advancing movement of the vortex as it is fed in from the fresh portions of the high. A West India hurricane moves westward in the westmoving tropical upper air, recurves around the edge of the great Atlantic high, and advances eastward in the mid-latitude eastmoving upper air, the low pressure being a symptom of this continuous stationary circulation, using the word stationary in its technical meaning given above.

Again, the rain areas are formed along the edges of the high, at a certain average distance from its center, the irregular patches occurring on the weather map being generally parts of such a formation. This is about the only rule in forecasting rain that is of real value and capable of serving on all occasions. Precipitation is apparently formed by the discharge of the cool upper air into the adjacent low stratum, the lowering of temperature by direct contact of masses of cool air with masses of warm moist air being evidently most efficient in producing the scattered rainfalls. Intimate mixture has some effect, radiation some, adiabatic cooling by expansion much, but in our judgment such direct contact cooling by the intermixture of large masses of air at different temperatures is the leading process, as evidenced by the data of the weather maps. This is especially vigorous in the

eastward quadrants of the lows, where the northwest cold dry current is intimately mixing in discontinuous shreds with the warm moist atmosphere from the southeast, this formation of currents being a vortical product. No doubt the rising air cools by expansion, but it is probable that the flowing together of these two sheets of air in the stratum about 1 mile high is chiefly instrumental in effecting rainfall. Warm moist air rising upward against an overflowing cold sheet is the best possible condition for rainfall. The thunderstorms and local storms of summer are associated with the southeast quadrant merely because the counterflows from the adjacent highs meet together in this region. It is of course admitted that the latent heat derived from the condensation of vapor in the atmosphere greatly strengthens the formation of the cyclonic vortices in the low areas and intensifies the violence of storms, but it is hardly a necessary feature in their formation, as numerous examples on the weather maps testify.

The primary principle of forecasting is, therefore: *Subordinate all weather features to the high areas, determine the movements and the action of the highs, deducing the effect of these upon each other in the counter-flow and along the isolated periphery.*

2. The next important principle in forecasting is the mode of determining the movements of the high-pressure areas. This depends upon two general systems of conditions: (1) The continental and oceanic areas, and (2) the configuration of the general circulation about the North American continent. The details must be learned by examination of the charts, viewed in their annual changes. In the winter the continent by its effect upon radiation, with the sun in the southern hemisphere, tends to build up strong, cold, high-pressure areas, and these are propagated south and eastward, in the northern or the southern circuits, as heretofore explained. In the summer the continent tends to build feeble, warm, low-pressure areas in the interior, with high areas bordering the coast districts, so that the circulation is from the oceans to the interior. The difference in the interpretation of the isobars is important, because a summer cyclonic circulation near the Rocky Mountains means little in the way of a general storm, though local storms, tornadoes, and thunderstorms may be produced. But in the winter the formation of a cyclonic circulation on the eastern side of the divide of the mountains is very likely to reach the ocean before dissipation, while in summer many such storms die out in the Lake region and the upper St. Lawrence Valley.

The movement of highs generally is decided by the peculiar intraction that exists between the great eastward drift in middle latitudes and the calm or stationary high that tends to build in the subtropical belt. If a high is caught firmly in the eastward drift, it will move over the northern circuit toward the great permanent cyclone of the North Atlantic Ocean; if it is needed to build into the tropical high-pressure

belt, it will move in the southern circuit to the Gulf States. One of the important problems of practical meteorology is to determine when the highs will take these courses, respectively. On reaching the Atlantic coast a double uncertainty overtakes the high movements—that is, they may settle from the north to the south, especially in summer, or they may be drawn from the south northward, particularly in the winter. During seasons of stagnant circulation they may linger many days upon the coast line, with a slight movement northward or southward. The second great principle is: *Determine from a knowledge of the general circulation the movement of the high areas in the northern or the southern circuits, and along the Atlantic coast line, as specified by the appearance of a given map.*

3. The next fundamental point to have in mind is the rapidity of the eastward drift, especially in the northern circuit. This is subjected to a succession of accelerations and retardations, rapid movements, and stagnant conditions, which are always very puzzling to the forecaster. It is clear that these must also be referred to the circulation of the upper strata to some extent, but our knowledge of this subject is so imperfect that no final statements can now be made regarding it. We may hope by patient observations of the cloud motions to ultimately bring this also within our understanding.

LONG-RANGE FORECASTING.

The advantages that would be derived from an ability to forecast weather conditions for considerable intervals in advance of occurrence are very obvious, especially to provide successful forecasts of the seasonal variations from year to year. Many attempts have been made to accomplish this result, but usually in so unscientific a way as to have discredited such efforts and to have brought the entire subject into disrepute. On this account the official forecasts of the Weather Bureau have been carefully confined to periods of forty-eight hours or less, and no definite forecasts have ever been published for the seasons of the year in advance. In truth, the difficulties to be overcome in order to make such forecasts scientifically are enormous, and they have not yet yielded to some very persistent labor. It is easily seen that a successful long-range forecast can be based only upon an accurate understanding of the laws of the general and also the local circulations of the upper and lower strata of the air as modified by the continents and the oceans; likewise it is necessary to know the exact relation that the solar energy bears to these atmospheric movements. Until the physical laws are fully in our possession and the result is such as to demonstrate the impossibility of seasonal weather predictions, it is allowable to indulge the hope that forecasts may some time be made to extend beyond the two-day limit now set.

To make an attack of importance upon this obscure region of meteorology it is first necessary to learn how to classify weather conditions

in order to study them properly, and this means the detection of all the fundamental periods. Besides the diurnal period depending upon the rotation of the earth on its axis and the annual period due to the revolution of the earth in its orbit around the sun there must be yet others which depend upon the action of the sun itself. One of these is the rotation of the sun on its axis, another the slow congestion of the sun's material in the 11-year period, and in the subordinate $2\frac{3}{4}$ -year period, and there may be also very long periods which can not be considered in this connection. It is clear that the calendar months, according to which our meteorological data are commonly collected, for which intervals the means are taken, have no natural periodic relation to the underlying phenomena, and that the customary method of operation tends merely to conceal any natural laws that may really exist in the periodic repetition of weather conditions. Hence it is of primary importance to discover an accurate fundamental period to substitute for the calendar-month system.

As the result of much work on the variations of the terrestrial magnetic field, it is concluded that such a period exists, dependent upon the rotation of the sun on its axis, giving a normal curve which tends to repeat itself in 26.67928 days. The curve is shown on Chart 18, and the following ephemeris gives the dates of the beginning of the same curve for the first period in each year for the years 1840-1899, inclusive. Other dates can be readily found throughout any year by adding 26.68 days successively to the January date of the given year.

Ephemeris of the synodic rotation of the sun.

[Period, 26.67928 days; epoch, June 13.72, 1887.]

Year.	Date.	Year.	Date.	Year.	Date.
1840.....	Jan. 16. 87	1880.....	Jan. 21. 99	1880.....	Jan. 27. 11
1841.....	Jan. 24. 38	1881.....	Jan. 2. 82	1881.....	Jan. 7. 94
1842.....	Jan. 6. 21	1882.....	Jan. 11. 33	1882.....	Jan. 16. 45
1843.....	Jan. 14. 72	1883.....	Jan. 19. 84	1883.....	Jan. 24. 96
1844.....	Jan. 23. 23	1884.....	Jan. 1. 67	1884.....	Jan. 6. 79
1845.....	Jan. 4. 06	1885.....	Jan. 9. 18	1885.....	Jan. 14. 30
1846.....	Jan. 12. 57	1886.....	Jan. 17. 69	1886.....	Jan. 22. 81
1847.....	Jan. 21. 08	1887.....	Jan. 26. 20	1887.....	Jan. 4. 64
1848.....	Jan. 2. 91	1888.....	Jan. 8. 03	1888.....	Jan. 13. 15
1849.....	Jan. 10. 42	1889.....	Jan. 15. 54	1889.....	Jan. 20. 66
1850.....	Jan. 18. 93	1870.....	Jan. 24. 05	1890.....	Jan. 2. 49
1851.....	Jan. 27. 44	1871.....	Jan. 5. 88	1891.....	Jan. 11. 00
1852.....	Jan. 9. 27	1872.....	Jan. 14. 39	1892.....	Jan. 19. 51
1853.....	Jan. 16. 78	1873.....	Jan. 21. 90	1893.....	Jan. 27. 02
1854.....	Jan. 25. 29	1874.....	Jan. 3. 73	1894.....	Jan. 8. 85
1855.....	Jan. 7. 12	1875.....	Jan. 12. 24	1895.....	Jan. 17. 36
1856.....	Jan. 15. 63	1876.....	Jan. 20. 75	1896.....	Jan. 25. 87
1857.....	Jan. 23. 14	1877.....	Jan. 1. 59	1897.....	Jan. 6. 70
1858.....	Jan. 4. 97	1878.....	Jan. 10. 09	1898.....	Jan. 15. 21
1859.....	Jan. 13. 48	1879.....	Jan. 18. 60	1899.....	Jan. 23. 73

Up to this point the investigation was not really difficult, but on applying the curve to current meteorological and magnetic phenomena a very surprising fact emerged into view for consideration. The observations during certain months followed the curve in the direct form given above and in other months in the form derived by inverting this curve on its long axis. There was also a certain looseness attending the matching of the normal curve to the individual repetitions as recorded in the observations, which sometimes made it difficult to decide whether the direct or inverse type was really represented, and this irregularity seemed to occur in a lawless way. It is easy to see that some of the causes at work to produce that effect are (1) the spasmodic and irregular action of the sun itself in producing an external field of magnetic force; (2) the variable action of the earth's atmosphere in forming the convection currents and the corresponding highs and lows; (3) the unsteady eastward drift; and, (4) the unknown forces of absorption and radiation at work in the atmosphere. Nevertheless, in hope of discovering the law of such reversals, the magnetic horizontal forces observed since the year 1841 were transferred from the published reports to curves plotted according to the periods of the ephemeris. Then the normal curve was matched with each period as impartially as possible and in such a manner as to leave the judgment unprejudiced, being repeated on different occasions, and marked D for direct type and I for inverse type. Then the number of D's in each of the 14 periods was counted up for the years 1841-1894, inclusive, and the result is recorded in the numbers at the bottom of Chart 19. This shows the tendency for the direct form to prevail in different portions of the year, and the inverse type is merely complementary to it. The representative line is evidently a semiannual periodic sine curve, repeated twice annually, and its relation to the sun's and the earth's equators is shown, these being placed in the position assumed in June for an observer looking at the sun from the earth. On Chart 20 the same curve is shown in its relations to the fundamental planes, Ecliptic K, Sun's Equator S, Earth's Equator E, wherein is seen the astronomical triangle and the nodal lines as derived from astronomical data. The direct type only is represented on the chart, but the inverse type bears a counterpart relation from right to left. The positions where these curves cut the ecliptic show the points where the two types are evenly balanced in a sort of penumbra. The solar force acts strongly enough at right angles and parallel to the solar axis to impress its type upon the terrestrial field; in the regions of transition the type is less clearly defined. The transition dates are near February 1, April 20, July 15, and October 15, on the average. The fact that this peculiar phenomenon occurs in terrestrial magnetic and also meteorological phenomena is very important. It implies that the storms of the northwest generate in an order influenced by the polar magnetic force from the sun.

It is necessary only to remark that the types appear to be determined

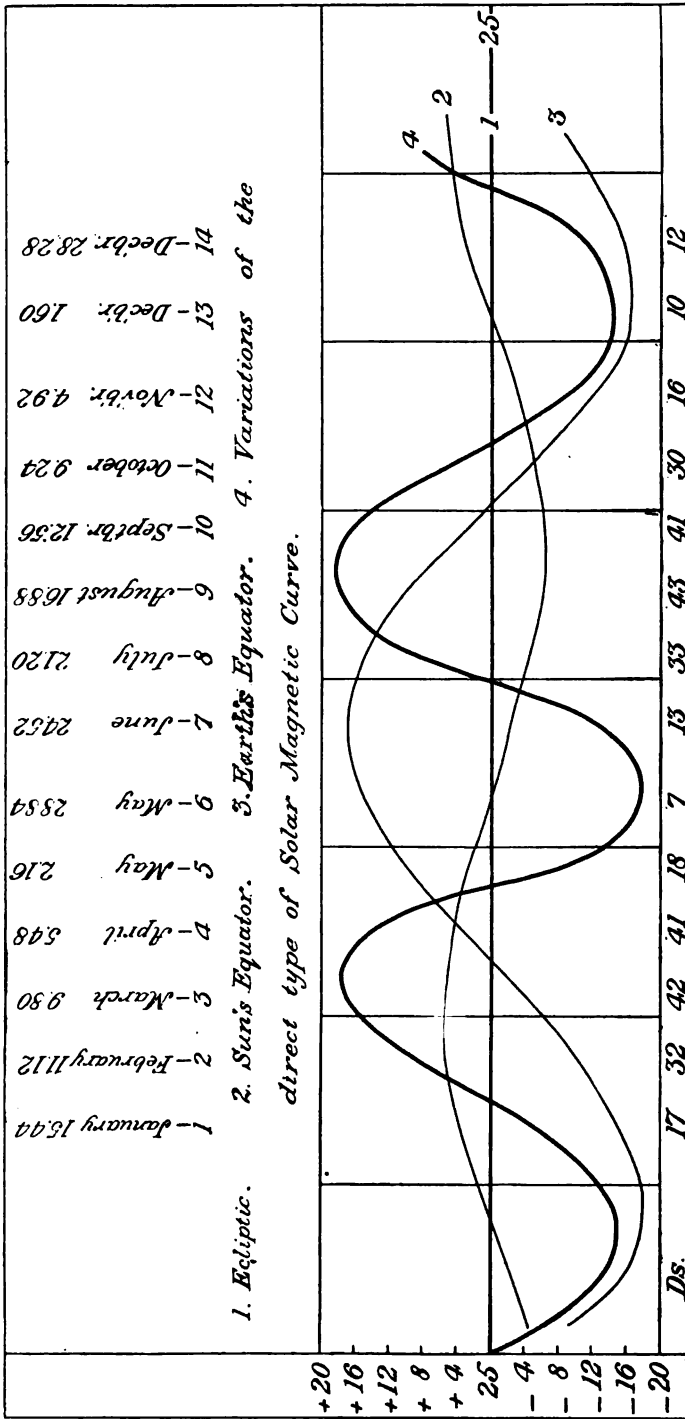


Chart 19.—Relative number of the direct type occurring annually, showing the semiannual periodic inversion. From the magnetic data 1891-1894.

by the position of the sun's axis projected on the ecliptic, the axis of type direct being perpendicular, and that of type inverse the parallel to that line. The physics involved in this relation can not here be given, but the main facts are evident enough: (1) We have therefore obtained a period of rotation for the sun that works without sliding for over fifty years; (2) also a well-formed curve, which, on the average, represents

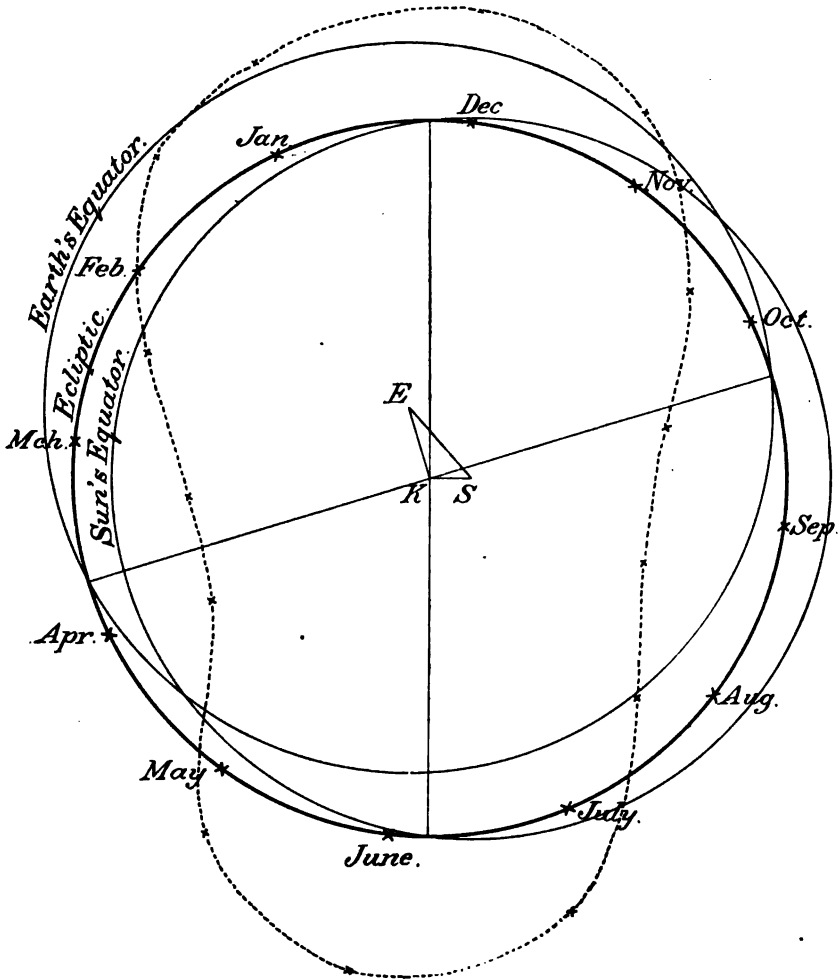


Chart 20.—Semiannual period in the inversion of the direct type of the solar magnetic curve.

terrestrial magnetic observations for this interval, and meteorological observations for at least twenty years; and (3) the peculiar law of inversion is such that the direct type prevails from about February 1 to April 20 and from July 15 to October 15; while the inverse type holds for the intervals April 20 to July 15 and October 15 to February 1.

We may therefore conclude that for a first approximation our process

of long-range forecasting should be as follows: (1) In any year find the dates of beginning of the normal curves from the ephemeris; (2) classify the data as direct or inverse as far as possible within the dates above determined for the maximum of D and I types; (3) for any given day read the slope of the curve as shown by the normal period in the extreme northwest, that is, in western Canada, or in the Dakotas, counted as one day elapsed; (4) allow as far as possible for the eastern drift in the northern or the southern circuits to any station for which forecasts are required. These are the first definite rules for scientific long-range forecasts; but considering the many elements of the problem yet undetermined, it is hoped that no one will expect too much of them, or be discouraged by failures.

SUMMARY.

A brief summary of the scheme of meteorological thought herewith presented can now be given: (1) The general circulation of the atmosphere has a downward component near the poles where the northward upper stratum returns into the lower southward current, its power consisting in slowing down the rapid eastward drift by diverting it into descending anticyclonic vortices; (2) these are localized upon the continents, chiefly in winter, by reason of the action of the land areas being colder than the oceans, wherefore highs tend to form in western Canada especially during that season; (3) the entrance of the earth into longitudes of the sun having a stronger magnetic field lowers the temperature in this region, and thus assists the tendency to form high areas at definite dates in the general subpolar circulation, it being more pronounced on the North American continent than elsewhere in the same high latitudes by reason of the presence of the magnetic pole near that place; (4) these highs drift southward and eastward within the great eastward upper current, being still fed by the general circulation, which itself is sustained from the tropical zones and continues to discharge downward into the highs by means of an anticyclonic stationary system of streams; (5) between successive highs is formed a low with cyclonic circulation, which, under hydrostatic pressure, aided by convective vertical components of warmer air, drives the air in stream lines back into the upper strata, there to be aimlessly destroyed in the rapid eastward currents; (6) the convective action in cyclones derived from local temperature and the latent heat of condensation of vapor in precipitation is an important incident, assisting gyratory vortex action, but after all only a secondary phenomenon; (7) this view admits the validity of Ferrel's analytical solution (also Overbeck's) of the *general* circulation of the atmosphere, but concludes that it is not strictly applicable to the local mid-latitude cyclones; that the general cyclone of the poles and the local cyclone with anticyclone surrounding it are not so parallel in theory as was supposed in the formulae. On the other

hand, the lows are not eddies in the upper currents, but more properly the highs are the eddies; actually they are stationary downward circulations in deflecting the direction of the upper into the lower strata, and the lows are secondary effects derived from these under the impelling forces of gravity and hydrostatic pressure. This explanation gives to the entire machinery of the atmosphere, it is believed, a logical and harmonious operation, and it certainly avoids some of the difficulties that are now felt by meteorologists.



U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

ABSTRACT OF A REPORT

ON

SOLAR AND TERRESTRIAL MAGNETISM

IN

THEIR RELATIONS TO METEOROLOGY.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau,

BY

FRANK H. BIGELOW,
Professor of Meteorology.



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1898.

LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF CHIEF OF WEATHER BUREAU,
Washington, D. C., November 1, 1897.

SIR: I have the honor to transmit herewith an Abstract of a Report on Solar and Terrestrial Magnetism in Their Relations to Meteorology, by Prof. Frank H. Bigelow, of the Weather Bureau, and recommend that it be published as a bulletin of the Weather Bureau.

Professor Bigelow has, during the past six years, devoted much time to the study of the fundamental principles of this important subject, and considerable discussion has ensued among scientific people in regard to the hypotheses assumed by him. He is of the opinion that the atmospheric conditions which culminate in the storms traversing the United States are in part dependent upon the solar energy that reaches the earth in the form of magnetic force; that there are synchronous fluctuations in the pressures and temperatures of the north-western regions of the American continent in the neighborhood of the magnetic pole and the auroral belt; that a train of storms, "highs" and "lows," advance from that quarter eastward in well-defined tracks; that the position of the tracks and the intensity of the storms change along with the strength of the solar magnetic field; that there are many other forces at work to produce storms, such as the general circulation of the atmosphere and the local convection of heat and aqueous vapor, but that among them all must be included the magnetic forces in order to obtain a correct understanding of the mechanism of cyclones and anticyclones.

It is my opinion that at this stage of the investigation the sequence of cause and effect is not shown with sufficient definiteness to justify the weather forecaster in attempting, with our present knowledge of solar and terrestrial magnetism, to apply these theories to the making of forecasts and warnings of marked atmospheric disturbances. However, it is believed that the paper which Professor Bigelow presents will so stimulate thought and discussion as to result in further additions to the knowledge of magnetic science.

Very respectfully,

WILLIS L. MOORE, *Chief of Bureau.*

Authorized:

JAMES WILSON, *Secretary of Agriculture.*

PREFACE.

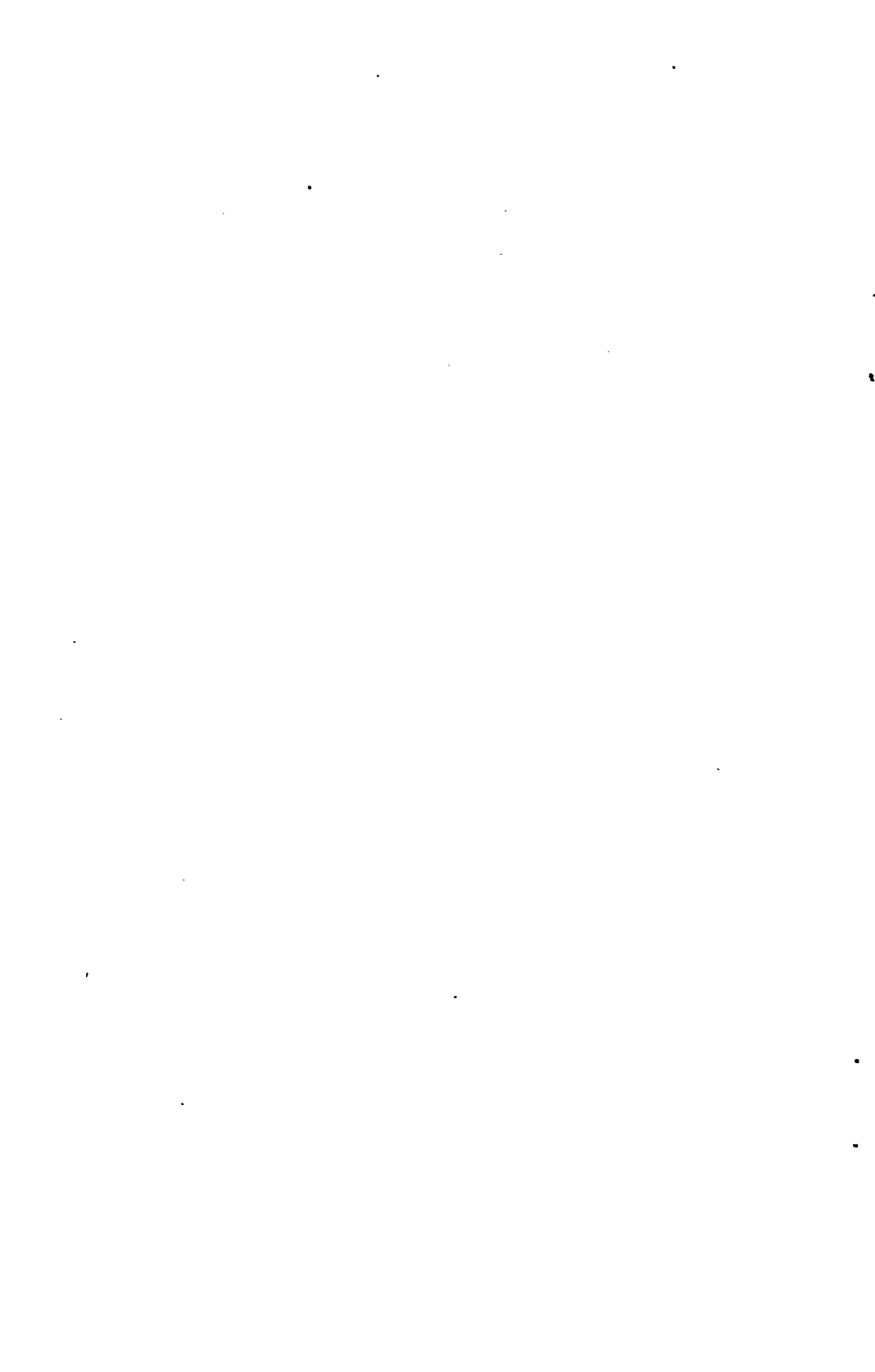
A remarkable feature of the history of terrestrial magnetism and also of meteorology is the fact that, in spite of many discussions of an enormous mass of observations, progress toward correlating them in general scientific laws has been very slow, the results in the main being unsatisfactory. The researches which I have conducted in these subjects have persuaded me that this has been largely due to erroneous points of view in two particulars. The first depends upon a premature rejection of the direct magnetic action of the sun upon the earth, as a working hypothesis; the second upon a too rigid application of the theory of the general circulation of the atmosphere over a hemisphere to the local cyclone in midlatitude zones. The authority given to these positions by their distinguished authors and advocates rendered it difficult to construct quite different plans of procedure, but it is believed to have been essential to do so in order to secure important advancement in these branches of science.

The exposition of these views embraces a series of papers arranged in parts.

I. Remarks on practical forecasting, which are embodied in Bulletin No. 20, United States Weather Bureau, entitled Storms, Storm Tracks, and Weather Forecasting, 1897, wherein the plan of the research is outlined in general terms.

II. Specific arguments and data in support of the doctrine of the direct magnetic action of the sun are contained in this Bulletin, No. 21, Abstract of a Report on Solar and Terrestrial Magnetism, together with their Relations to Meteorology, 1897.

III. Specific arguments and data in favor of the view that the fundamental equations of the general and the local cyclones are not strictly identical will be given in a paper, now in preparation, on the Circulation of the Atmosphere over the North American Continent.



CONTENTS.

	Page.
CHAPTER 1. INTRODUCTORY REMARKS ON MAGNETISM AND METEOROLOGY.	
Citation of opinions as to the connection between certain solar and terrestrial phenomena.....	13
Remarks on four working hypotheses.....	15
Examination of four arguments used against the hypothesis of the direct magnetic action of the sun.....	16
Review of the status of the earth magnetic problem.....	20
General nature of the problem.....	23
Summary of the results of previous researches.....	25
Method of computing the magnetic observations.....	27
Difficulty of finding the rotation period of the sun.....	29
Nomenclature, definitions, and type magnetic-force diagrams.....	31
Some reasons for the slow development of the science of terrestrial magnetism.....	41
Diagrams giving the leading features of the component magnetic polar fields.....	42
CHAPTER 2. DETERMINATION OF THE 26.68-DAY SOLAR MAGNETIC PERIOD.	
Elements of computation for 11 stations, March, 1887.....	45
Discussion of the results of the tabulations.....	47
Mean value of the angle α for the European field.....	48
Mean value of the angle β_1 for the European field.....	49
Periodic reversal of the azimuths of the deflecting forces during 1887.....	50
Approximate values of the 26.68-day period; a trial ephemeris.....	57
Four parallel systems of dates; equations of condition; normal equations and solution.....	58
CHAPTER 3. ANALYSIS OF THE POLAR MAGNETIC FIELD ALONG THE TERRESTRIAL MERIDIANS.	
Example of the computation for Fort Rae.....	61
Extension of the computation to 26 stations.....	63
Discussion of the results; the aurora belt; the permeable shell.....	63
Formulae for the magnetic systems.....	65
Chart of combined exflected and inflected systems.....	70
Disturbing vectors during the great disturbances of January 4, January 28, and February 13, 1892, at 10 stations.....	72
Different systems used in the instrumental records.....	72
Process for eliminating the true disturbance ordinates.....	75
Components of the lines of a spherical magnet in a uniform field.....	78
Criticism of other theories to account for the variations of the earth's magnetic field.....	79

CHAPTER 4. DEFLECTING FORCES OF THE EQUATORIAL ELECTROMAGNETIC FIELD.	Page.
Determination of the vectors emanating from the electromagnetic system.....	81
A permeable shell inclosing a sphere magnetized at right angles to an external field.....	83
Computation of the vector system for Jan Mayen.....	83
The 30-inch globe constructed from the vectors at 30 stations.....	85
Description of the forces of this magnetic system.....	89
Change of the entire vector system in latitude with the sun's declination.....	93
CHAPTER 5. SOME RELATIONS BETWEEN THE VARIATIONS OF THE TERRESTRIAL MAGNETIC FIELD AND THE METEOROLOGICAL ELEMENTS.	
Method followed in comparing the magnetic and meteorological data.....	94
The phenomenon of the inversion of the normal curve.....	99
Discovery of the law of inversion.....	100
Synchronism of the magnetic and the meteorological elements in the 26.68-day period.....	108
Synchronism of the same in the 11-year period.....	121
Relative efficiency of the several forces.....	126
Some miscellaneous data, showing synchronism in the 26.68-day period.....	129
CHAPTER 6. SOLAR MAGNETISM.	
The solar coronas of July 29, 1878, January 1, 1889, and December 22, 1889.....	131
The sun-spot areas in the 26.68-day period.....	140
The variations of latitude in Chandler's period.....	146
The law of the inversion of the normal type curve.....	147
The elements of the sun and the earth as magnets.....	164
The two types of radiation, electromagnetic and magnetic.....	166
Recomputation of solar values of E. H.....	170
The functional variations in the magnetic and the meteorological elements.....	172
General relations to the Gaussian potential of the earth and its secular variations.....	173
Summary.....	174

TABLES.

TABLE 1. Sidereal and synodic periods of rotation of the sun.....	29
2. The mean deflecting forces in rectangular and polar coordinates for Greenwich, March, 1887.....	41
3. Data for reduction of factors of C. G. S. units, from reports for March, 1887.....	45
4. Computed values of σ, s, α, β for several stations, March, 1887.....	46
5. Angle α for European stations.....	49
6. Computed values of β_1 , for the year 1887 at several stations, showing the reversals in azimuth of the deflecting force.....	51
7. Method of deducing the trial period and ephemeris.....	58
8. Formation and solution of the equations of condition.....	59
9. Deflecting forces at Fort Rae separated into the southward and northward groups.....	61
10. Mean deflecting forces at 26 stations.....	63

TABLE 11. Formulæ:

	Page.
1. Uniformly magnetized sphere	66
2. Uniformly magnetized sphere in a uniform field	67
3. Inflected and exflected magnetic systems	68
12. Computed ordinates y	70
13. The arrangement of the photographic traces	72
14. Ordinates in millimeters for the diurnal variations in H. D. V	74
15. Deflecting forces during the great disturbance, February 13, 1892 ..	76
16. Mean values of s , α , β	77
17. Coordinates of the magnetic elements at 30 stations	84
18. Diurnal deflecting forces at Jan Mayen	84
19. Deflecting vectors of the equatorial electromagnetic field, measured on the 30-inch globe model	87
20. Variations of the horizontal component σ , for 1878 and 1882	96
21. Four systems of direct and inverse type	101
22. Variations of the northwest pressures for 1878 and 1882	110
23. Variation of the northwest temperatures for 1878 and 1882	110
24. Summary of the horizontal component σ	112
25. Summary of the northwest pressure variations	112
26. Summary of the northwest temperatures	114
27. Determination of the normal solar curve	118
28. Ephemeris and adopted form of the normal periodic curve	120
29. Mean annual and periodic values:	
1. European horizontal component σ	122
2. Northwest pressures	122
3. Northwest temperatures	123
4. Northwest pressure amplitudes	123
30. Comparison of the secular variations of the sun spots, the European magnetic field, and the American meteorological system	124
31. The solar magnetic force, West Indies hurricane frequency movement in longitude, and number of highs and lows in the 26.68-day period	128
32. Computed polar distance of the base of the visible rays of three coronas	136
33. Computation of the longitudes of the coronal poles at seven eclipses between 1878 and 1893	138
34. Sun-spot areas distributed in the 26.68-day period, for the Northern Hemisphere	142
35. Same for the Southern Hemisphere	144
36. Magnetic elements of the earth in the C. G. S. system	165
37. Magnetic elements of the sun in the C. G. S. system	165
38. Recomputation of Maxwell's values of E and H for Langley's value of the constant of solar energy	171

ILLUSTRATIONS.

CHART		Page.
1.	Coordinates of normal and deflecting magnetic forces.....	32
2.	Uniform field	34
3.	Unipolar field.....	35
4.	Bipolar field or doublet	36
5.	Uniformly polarized sphere.....	37
6.	Doublet in a uniform field, stable position.....	38
7.	Doublet in a uniform field, unstable position.....	39
8.	Typical lines of the earth's field as deflected by the solar field.....	43
9.	Periodic variations in the strength of the solar field as observed within the earth's field. Direct and inverse types.....	44
10.	Vectors of the polar magnetic field derived from observations.....	64
11.	Magnetic lines through a permeable shell.....	71
12.	Components of the impressed forces disturbing the earth's field, in both north and south directions.....	78
13.	Schematic distribution of the disturbing vectors of a magnetized sphere, covered by a permeable shell, immersed in an external magnetic field and at right angles to it.....	82
14.	Deflecting forces of the electromagnetic field with the sun on the central meridian.....	88
15.	Deflecting forces of the electromagnetic field in the north magnetic hemisphere	89
16.	Scheme of the directions of the deflecting forces of the diurnal variations	90
17.	Variation of the horizontal force, direct type.....	100
18.	Variation of the horizontal force, inverse type.....	100
19.	Semiannual period of the inverse type.....	106
20.	Semiannual period of the inverse type, projected upon the ecliptic.....	107
21.	26.68-day solar period, direct type.....	116
22.	26.68-day solar period, inverse type.....	116
23.	Direct type of the variation of the magnetic and meteorological elements in the 26.68-day periods. Old and new epochs	119
24.	Diagram of the relative secular variations in the sun spots, the European magnetic field, and the American meteorological system.....	125
25.	Diagram of the magnetic force, hurricane frequency, movement in longitude, and number of highs and lows in the 26.68-day period.....	129
26.	Comparison of the model of the solar corona with the coronal lines for the eclipse, July 29, 1878.....	132
27.	Same for the eclipse, January 1, 1889	133
28.	Same for the eclipse, December 22, 1889.....	134
29.	Comparison of the total sun-spot areas, 1854-1891, with the normal curve of the 26.68-day period	141
30.	Comparison of the sun-spot frequencies with Chandler's long-period latitude variation.....	147
31.	Resolution of forces in a doublet.....	150

CHART 32. Application of Gauss's theorem to the construction of a magnetic oval at the point $r=208$, $\theta=80^\circ$	151
33. Relation of the lines of the magnetic ovals to the earth's axis, at four points in the orbit.	152
34. Resolution of forces in an induced doublet.	156
35. Magnet in earth's field, stable position	159
36. Magnet in earth's field, unstable position	160
37. Magnet in earth's field. North end to the left.....	161
38. Magnet in earth's field. North end to the right.....	162
39. Magnet in earth's field. Lines distorted by two couples at the angle 10 degrees	163

CHAPTER 1.

HISTORICAL INTRODUCTION. METHOD OF COMPUTING THE TERRESTRIAL MAGNETIC DEFLECTING VECTOR SYSTEMS.

That there is a causal connection between the observed variations in the forces of the sun, the terrestrial magnetic field, and the meteorological elements has been the conclusion of every research into this subject for the past fifty years. The elucidation of exactly what the connection is and the scientific proof of it is to be classed among the most difficult problems presented in terrestrial physics. The evidence adduced in favor of this conclusion is on the whole of a cumulative kind, since the direct sequence of cause and effect is so far masked in the complex interaction of the many delicate forces in operation as to render its immediate measurement quite impossible in the present state of science. Before attempting to abstract the results of this research on these points a brief résumé of the views held by the leading investigators will be given, especially with the object of presenting the status of the problem to those who are not fully acquainted with this line of scientific literature. The bibliography is large—covers a century—and embraces such names as Humboldt, Gauss, Sabine, Lamont, Faraday, Wolf, Ellis, Broun, Hornstein, Stewart, Schuster, Capello, Meldrum, Airy, Walker, van Bebber, Lemström, Fritz, Loomis, Kelvin, and many others.

CITATION OF OPINIONS AS TO THE CONNECTION BETWEEN CERTAIN SOLAR AND TERRESTRIAL PHENOMENA.

Walker expresses his conclusion regarding the main point as follows, page 103:¹

The almost exact coincidence, so far as hitherto observed, between the *periods* and *turning points* of three classes of phenomena at first sight so widely different, as the magnetic *disturbances*, the *diurnal range*, and the *frequency of solar spots*, can, I think, leave no reasonable doubt that this coincidence is *causal*, and not *accidental*. This fact, as Humboldt remarks, gives a very high cosmical interest to the study of terrestrial magnetism.

Lemström summarizes his own and current opinion in this way, page 24:²

We borrow from Loomis a graphic representation of the phenomena, the number of auroras observed annually, the mean deviation of the magnetic needle, and the relative extent of the solar spots, which shows perfectly their accord from 1780 to 1870.

¹ Terrestrial and Cosmical Magnetism, Adams prize essay, Walker.

² L'aurore boréale, M. Lemström, 1886.

The meteorological observations on which we can make computations embrace a period of time too short to enable us to establish with certainty the laws which regulate the changes of the atmosphere. But on comparing the observations of the perturbations of the atmosphere called cyclones or storms a periodicity is found which probably accords with the eleven-year period already mentioned. Fritz has indicated in his memoirs three remarkable results, which we will cite:

"1. During the time when the sun spots are at their maximum, the rainfall, snow, and hail are more abundant than during the time of minimum.

"2. The variability of the pressure of the air changes, also, in parallel with the great periods of the aurora borealis and the sun spots.

"3. Hurricanes and violent movements in the air are more frequent at times of maximum than at times of minimum spots, and on the other hand fair weather is more abundant in the latter case than in the former."

It is evident that if there is a close relation among these phenomena, it ought to be shown also in the quality of the harvests. (Compare Lemström's paper read at the Chicago Congress, 1893). We are then entirely in agreement with the general result of Fritz, that there is certainly a relation between the variability of the sun spots, the magnetic declination, and the number of the auroras; also, that similar relations with the meteorological phenomena are very probable.

W. J. van Bebber investigates carefully the meteorological side of the question with the following conclusion, page 258,¹ which is also quoted by Sprung in his meteorology, page 366:²

It appears to us undoubted that relations exist between the sun spots and meteorological phenomena, which if their characteristics and amount were known could be sometimes employed with success in our forecasts of the weather. It is probable that the periodic changes in the atmosphere are not brought about directly through the sun spots, but that both phenomena are produced by a common underlying agency whereby the synchronous variation in periods is possible.

He specifies such changes in the atmosphere along with the sun spots, as the temperature and pressure, cyclones and winds, precipitation, cloudiness, thunderstorms and hail, and concludes—

Therefore it is not to be denied that there is a connection between sun-spot frequencies and the changes in our atmosphere, only the periodic movement of the weather phenomena is beset by so many unknown kinds of disturbances that it is not now possible to make successful long-range forecasts from them.

Ebert introduces a section on "Magnetism as a cosmical force," as follows, page 55:³

We can not directly point out magnetic action of an extra-terrestrial source, but we recognize in the variable state of the body of our earth undoubtedly the play of cosmical forces. Especially, the so-called disturbances in the terrestrial system of the lines of force can probably be referred to the impressed action of the external heavenly bodies. Thus magnetism is a powerful cosmical bond which unites world with world.

The most comprehensive summary of the experimental and speculative aspects of the problem up to about fifteen years ago is to be found in the ninth edition of the *Encyclopædia Britannica*, article "Meteorology," by Balfour Stewart, where the complexity pertaining to the

¹ Handbuch der ausübenden Witterungskunde, W. J. van Bebber, Stuttgart, 1885.

² Lehrbuch der Meteorologie, A. Sprung, Hamburg, 1885.

³ Magnetische Kraftfelder, H. Ebert, Leipzig, 1896.

entire subject is presented to the reader. In order to concentrate our discussion, that article will be chiefly referred to as containing generally those views of the subject which it has been the object of this research to improve upon as far as possible. Our critical remarks are intended to be directed against these expressions by Balfour Stewart specifically only in so far as they broadly represent the opinions of investigators. After reviewing the evidence his final summary is, page 181:

On the whole, we may conclude that the meteorological motions and processes of the earth are probably more active at times of maximum sun spots and that they agree with the magnetical phenomena in representing the sun as most powerful on such occasions, although the evidence derived from meteorology is not so conclusive as that derived from magnetism.

REMARKS ON FOUR WORKING HYPOTHESES.

This is a fair, conservative estimate of the value of the data presented in preceding investigations. The problem now before us is to bring the subject one stage nearer to demonstration and also to extract a useful working process that will contribute to weather forecasting, especially for the United States. As preliminary remarks I make the following observations: There are four historical leading working hypotheses regarding the mode of the physical connection, during the synchronous states of the sun and the earth referred to above, namely, (1) the direct magnetic action of a solar field upon the terrestrial magnetic field; (2) assumed electric currents in the upper atmosphere, due to the convective currents of circulation; (3) Faraday's displacement currents of magnetism, due to the local and general heating of the oxygen of the atmosphere; (4) the thermoelectric currents in the body of the earth. It may be presumed that future discussion will be limited to the first and second views, namely, (1) the direct action of a solar magnetic field, and (2) the indirect effect of the radiation of the sun transmitted to the earth's magnetic field by convective air currents. Whatever truth may attach to the second view, the object of this paper is to uphold the first view as of primary importance. It is not, perhaps, possible now to discriminate accurately to what extent the second view expresses some of the facts of nature, but it is my judgment that the first view was prematurely rejected, in consequence of two or three papers written on the subject, and that the evidence in favor of it has not been suitably considered. It is one of the cases where observational data must outweigh academic discussion. Probably the apparent strength of the second view lies in the process of exhaustion, which, excluding the other theories, left it standing alone, although it may have, in fact, such arguments in its favor as entitle it to respectful consideration.

Balfour Stewart's careful summary of his knowledge of the variations of the terrestrial magnetic field produces upon the mind of the reader only a hazy conception of the causes at work, and shows that the sub-

ject needs further analysis for its satisfactory elucidation. This could long ago have been readily accomplished by constructing the systems of deflecting vectors operating upon the earth's field, as in this paper. The prevailing method of discussing the variations of the component magnetic elements one at a time, however, obscured the solution. The analysis in the following chapters shows that these disturbing vector systems are such as will be produced if the earth, as a permeable shell, is placed in two magnetic fields, with their axes at right angles to each other: (1) the first axis parallel to the ecliptic, and the field causing the diurnal deflections of the needle, as well as the annual changes by its movement in latitude along with the declination of the sun; (2) the second field being perpendicular to the ecliptic, primarily static and steady, but transmitting large and small perturbations, the great departures from the normal state of the polar field causing the observed disturbances at the several stations. Having these concepts in mind, it is easy to see that many of the perplexities that pervade Balfour Stewart's statement of the case readily clear themselves up, though it would require more space than is appropriate in this abstract to review each point in detail.

An effort must be made to counteract the arguments that have been widely accepted as conclusive against the hypothesis of the direct action of the sun as a magnet on the earth's magnetic field and as the true source of some of the observed deflections of the needle. It seems to be the best course to endeavor to supplement any arguments with such positive proof of direct action in our observed phenomena as will necessarily carry along conviction of the fact itself. The remainder of this paper apparently contains such a demonstration, and therefore renders further argument superfluous. But first it may be well to examine briefly the negative arguments which now stand in the way of the acceptance of this view as the proper explanation of some of the observed changes in the terrestrial magnetic field.

EXAMINATION OF FOUR ARGUMENTS USED AGAINST THE HYPOTHESIS OF THE DIRECT MAGNETIC ACTION OF THE SUN.

1. *Temperature argument.*—It is stated by Balfour Stewart as follows (Enc. Brit., p. 181):

We have not advocated any direct magnetic action of the sun upon the earth, because from what we now know of the sun it appears to us unlikely that it should exercise an influence of this nature upon the earth, since a body at a high temperature possessing very strong magnetic properties is unknown to us.

It is evident that the *earth itself* was overlooked in this connection. According to received geological evidence, the interior of the earth is excessively hot, and yet a permanent magnetic field of considerable intensity is sustained by it, the field apparently having its seat in the material which constitutes the earth's nucleus. We shall show later on that the lines of the external fields in which the earth is immersed are

deflected around a large nucleus, and their configuration no doubt outlines the extent of the heated material. An ordinary steel magnet is merely an induced arrangement of molecules and does not exhibit exclusively all the possible magnetic states of the matter. There is no necessary inference to be drawn from common magnets, in their relation to temperature changes, that such primary bodies as the sun may not possess magnetic force among their potentialities, even at high temperatures. When the deflecting force of a magnet diminishes under an increase of temperature of the medium in which it is immersed the nature of the lines of force in the medium, as well as the molecular structure within the magnet, are to be considered. Whenever physicists explain the real nature of the ether stresses constituting a line of magnetic force we may take the next step in clearing up this difficulty. At present we know at least that an increase of temperature diminishes the strength of the magnetic field; on the other hand, that an increase of the strength of the field diminishes the temperature of the medium. The immediate line of argument followed in this paper is, the simple fact that increase of strength of the solar magnetic field is accompanied by a lowering of the temperature of the atmosphere, and hence by an increased tendency to build high-pressure areas, in the convectional circulation, especially in certain well-defined polar localities.

2. *The diurnal variations argument.*—In the Phil. Trans. 1863, p. 503, Charles Chambers, in his paper "On the nature of the sun's magnetic action upon the earth," argues from the comparison of certain component forces derived from the sun as a magnet, with the observations at two stations, Toronto and St. Helena, that the evidence is against any appreciable direct action. (26.27). It may be pointed out in reply that the conception of the origin of the disturbing forces employed in that paper *does not apply to the diurnal variations at all*, because, as will be shown, the diurnal vector system depends exclusively upon the sun's electromagnetic or sunlight field, which is a radial field and apparently induces in the ether an efficient polarization, in respect to exploring magnets on the surface of the earth. Chambers thought that the diurnal variations of the needle and the disturbances had the same source; it is our purpose to show that they have different sources, and that the failure to explain the diurnal variation by direct action of the sun as a magnet is really no argument against such action if it shows itself as a different vector system. Hence the logic of that paper is in fault, if the position taken in this report is correct. Airy's conjecture of a "magnetical ether," (same vol. Phil. Trans., p. 646,) is much nearer the mark. Since Maxwell and Hertz have given evidence of the existence of such an electromagnetic field, the burden of proof is precisely the other way. We should expect to find marks of the action of this radiant magnetic field on the normal magnetic field of the earth, and my analysis of observations is wholly in accord with

such possible effects. The diurnal variations of the needle are not due to the direct magnetic action of the sun by means of an ordinary curved polar field, but they are the results of the stresses of the ether, polarizations or displacements, caused by the immensely rapid electromagnetic vibrations, whose magnetic induction integrates into a practically steady field, relatively to magnets of more than atomic dimensions.

3. *The argument that this hypothesis is unnecessary.*—Balfour Stewart says, in *Enc. Brit.*, p. 181:

In fine, without presuming to deny the possibility of unknown influences of this nature, it does not appear to us that the time has arrived when we are called upon to resort to such as necessary aids to the discovery of further truths.

This implies the consideration that the ordinary diurnal variations and the disturbances find their explanation in the assumed electric currents of the upper air, due to the convectional currents of the atmospheric circulation. We have to remark that the difficulty which he mentions in section 121 of conceiving such a system of currents as would account for the facts, is pushed to the point of breaking down this second hypothesis by the analysis of the following chapters. The systems of currents supposed by him in sections 125 and 132 can not be made to conform to the complicated requirements of the case. Considering the great complexity of the vector systems, taken separately, charts 8 to 16, inclusive, we have only to add that these must be superposed upon each other and accounted for together by the proposed system of electric currents. It will be shown in the last chapter that there is yet another important term to be introduced, namely, the periodic inversion of the deflecting forces, before the observed disturbances are fully explained. The needle experiences the diurnal deflection at any given station by the action of the electromagnetic vector system; this changes with the seasons of the year, because the aspect of the earth's field goes through an annual period relatively to the axis of the radiantly polarized ether; superposed upon this is the polar magnetic field, bearing the normal variations from longitude to longitude on the sun; likewise the great disturbances which widely deflect the needle, according to the usual laws of the composition of forces; finally, the annual change of the aspect of the earth's field to this polar magnetic field introduces a modification which will be considered under the subject of inversion of type. Now, when we attempt to refer the almost continuous fluctuations of the polar-magnetic field, with its minute interactions on the other fields, namely, the normal terrestrial and the solar electromagnetic at the several stations in each hemisphere, it may be said that anyone familiar with the facts will despair of locating the electric currents in the earth's upper atmosphere, capable of inducing these magnetic forces, not to speak of assigning suitable physical causes for the currents themselves.

This difficulty is greatly increased when we compare the electric currents equivalent to the given magnetic vectors, and which may possibly

be mapped out, with the observed currents of the meteorological atmospheric circulation. That some impulses derived from the systems of impressed external magnetic forces should exist within the earth's atmosphere, especially at the sensitive spots, is certainly rational; long continued and general movements of the air may correspond with the permanent conditions of the solar field; but to suppose such a vibratory atmospheric circulation as matches the quick periodic and aperiodic changes observed in the earth's magnetic field demands, at least, a specific description of the atmospheric currents involved in the operation. The more we pass from vague general ideas about these currents to details, the less appears the probability of the truth of the second hypothesis, as the cause of the phenomenon.

4. *The intensity of solar magnetization argument.*—The note by Prof. W. Thomson, Phil. Trans. 1863, p. 515, has been many times repeated in substance in various forms, namely, that any reasonable magnetization which can be assigned to the sun is incompatible with the effects observed in the earth's magnetic field, especially during disturbances.

Formula for equatorial force.

$$\left[F_e = \frac{4}{3} \pi \frac{R^3}{r^3} I, \text{ for } \theta = 90^\circ. \right]$$

Formula.	F_e	I	I .079	I 1390	$r = 92,897,000$ miles. $R = 433,250$ miles.
Normal.....	0.00035	824	10430	0.59	} $r = 214.4$
Storm.....	0.00500	11768	148960	8.47	

The two cases of the normal field and the severe disturbances will be shown in the computations of chapter 4 to give, at the earth's distance from the sun, and for the sun's polar distance $\theta = 90^\circ$, $F_e = 0.00035$ and 0.00500 C. G. S., respectively. The magnetization of the sun by the usual formula as above is about 800 and 12,000 C. G. S., respectively; this is 10,000 and 150,000 times the magnetization of the earth; *only 0.6 and 8.5 times that of saturated steel*. The observations show that usually the magnetization of the sun is less than that of steel, but may become ten times as much in extreme disturbances. Professor Thomson said in the note referred to, "the sun's magnetism would therefore need to be 120 times as intense as the earth's to produce a disturbance of 1' in declination even by a complete reversal in the most favorable circumstances." The observational data leads us to believe that the sun is continuously magnetized about eighty times as strong as this specified amount, and therefore we conclude that this negative argument is not such as to exclude the hypothesis of direct action. The upper limit, ten times that of steel, we need not reject as irrational. It may lead to some revision of current theories regarding the magnetic nature of solar material, but that is, under the circumstances, the most plausible course to pursue.

REVIEW OF THE STATUS OF THE EARTH MAGNETIC PROBLEM.

A brief review of the results of several recent discussions of the earth's magnetic potential may serve to exhibit more clearly the bearing that this investigation has upon the solution of the problem in general. Gauss made an important advance over his predecessors by applying the harmonic analysis to the distribution of the earth's potential. Approximate reproductions of the normal terrestrial magnetic field had been made (1) by substituting hypothetical, small magnets near the earth's center; (2) by the method of distributing magnetic material on the surface; (3) by the method of displacement, and (4) by the equivalent electric currents circulating around the magnetic axis. These suppositions approximated only roughly to the observed values of the magnetic forces. Gauss assumed that the earth has a magnetic potential, that it is heterogeneous, wholly within the surface and, carrying the solution to the terms of the fourth order, found a result in better agreement with the observations. (*Gauss. Allgemeine Theorie des Erdmagnetismus*, 1838.) After the lapse of thirty years Erman and Petersen availed themselves of the large number of additional observations which had been made, and repeated the harmonic computation along lines similar to that of Gauss. They hoped that a substantial improvement would be possible by the use of more accurate observational data, and in this they were partially successful. (*Erman und Petersen. Die Grundlagen der gaussischen Theorie und die Erscheinungen des Erdmagnetismus im Jahre, 1829; Berlin, 1874.*) The comparison is given in their Table 13 between the old and new theories, but it is clear that the residuals are still too large to be considered satisfactory.

The next advancement was made by Professor Schuster in his paper on the "Diurnal variation of terrestrial magnetism" (*Phil. Trans. Roy. Soc. London*, 1889), in which he modified the theory that the potential is confined to the inside of the earth and computed the potential of the disturbing forces of the diurnal variation on two suppositions, (1) that it is inside, and (2) that it is outside the earth. His conclusion is as follows, page 468:

The agreement seemed to me to be sufficiently good to justify the conclusion that the greater part of the variation is due to causes outside the earth's surface. * * * The results of the calculation point not only to an external source, but to an additional internal source, standing in fixed relationship to the external cause. This we might have expected. A varying potential due to external causes must be accompanied by currents induced in the earth's body, which, in turn, must affect the magnetic needle.

The author attributes this external potential to electric currents in the atmosphere, made possible by its being in a peculiarly "sensitive state." I shall venture to suggest one or two criticisms on this valuable paper: (1) Schuster depends upon four stations—Bombay, Lisbon, Greenwich, and St. Petersburg—for the coefficients of the diurnal variations, these belonging to the midlatitude belt, and having, *by chance*,

the same distribution of the *vertical* component. But by comparing my globe model (see chapter 4) with them, it is seen that the *total* vectors are quite differently disposed in the equatorial zone and entirely different in the polar zone from those in the midlatitude zone. In short, Bombay should not be included with the other stations in the same vector system. It appears, therefore, that his extrapolation from pole to pole, page 477 et al., was not proper, the reduction given being true for the midlatitude zones, north and south, and only approximately so near the equator.

On comparing his fig. 12, page 508, with the globe model, it is perceived that we have arrived at nearly the same distribution of the vertical components, after translating the stream lines of Schuster's current function into equivalent magnetic force; but the vectors are really very different, because the horizontal component is lacking in his diagram. There is, undoubtedly, an exceedingly close connection between the diurnal circulation of the winds and this magnetic distribution, as Schuster mentions, in the midlatitude and also in the polar zones. My belief is that this convectional circulation of the atmosphere is the cause of the shifting of the magnetic system from a symmetrical distribution about the noon meridian into the observed eccentric position. It might plausibly but incorrectly be interpreted as a lag angle due to the rotation of the earth. According to cloud observations, at the 10 a. m. hour there is formed a circulation like a high-pressure area, and at 6 p. m. another like a low-pressure, the winds circulating from the high to the low by two paths, the short one from west to east across the noon meridian, and the second by a longer path crossing the midnight meridian. The subject is interesting but difficult, and is reserved for further examination in connection with our cloud observations.

In order to account for the electric currents, Schuster works out another hypothesis, namely, the theory of the earth as a magnet rotating in a medium of electric conductivity, in *Terrestrial Magnetism*, vol. 1, p. 1, on "Electric currents induced by rotating magnets, and their application to some phenomena of terrestrial magnetism." The conclusion is that some evidence exists for the conductivity of the ether, and if this is the case it is in harmony with the observed phenomena of the secular variation of the earth's magnetism. Whatever truth may finally be awarded to these two working hypotheses of Professor Schuster, it is proper to state the position assumed in this bulletin as a substitute for them, especially as the theory of electric currents in the upper atmosphere is quite commonly adopted as the explanation of the observed phenomena. The actual facts can be accounted for either by an external magnetic field or by an equivalent system of electric currents. The variation of either of these systems of forces induces currents in the earth, which, in turn, affect the position of the needle. *My effort has been to endeavor to show that this external field has characteristics which are entirely incompatible with a field induced by electric*

currents whose seat is within the earth's atmosphere. The phenomena of periodicity in solar periods and of inversion of the typical curve semi-annually are regarded as evidence of this position. This thesis will be maintained in the following pages.

Adolf Schmidt has recently completed a rediscussion (Neue Berechnung des Erdmagnetischen Potentials, 1895) in which distinct provision was made in the harmonic analysis for (1) an inside potential, (2) an outside potential, and (3) for vertical earth-air electric currents. His conclusion is as follows, based upon the best series of observations available, and including harmonic terms of the sixth order:

Die empirisch festgestellte Verteilung der erdmagnetischen Kräfte in der Erdoberfläche, wie sie durch Dr. Neumayers Karten für den Augenblick 1885.0 dargestellt wird, beruht zwar vorwiegend auf Ursachen, deren Sitz im Erdinnern liegt, kann aber nicht ausschliesslich auf solche zurückgeführt werden. Ein kleiner Teil der Kraft (etwa 1-40 des ganzen Betrages) ist Ursachen ausserhalb der Erdoberfläche zuzuschreiben; ein weiterer, noch etwas grösserer Teil (auf eine Fläche von einem Quadratkilometer kommt daher durchschnittlich ein Strom von 1-6 *Ampère*) deutet auf elektrische Strömungen hin, welche diese Fläche durchdringen.

It may be noted (1) that Professor Rücker concludes his discussion of the results of the magnetic survey of Great Britain as follows: "The local magnetic surveys furnish no evidence of vertical electric currents in the United Kingdom" (Terr. Mag., Vol. I, p. 83); (2) that Dr. Bauer, from summations of magnetic circuits on the earth's parallels, the data being drawn from observations compiled into charts, finds, "apparently, an appreciable part of the earth's total magnetism can be referred to an effect similar to that of vertical electric currents. The average intensity of these currents for the region between 60° N. and 60° S. would be about one-tenth of an ampère per square kilometer of surface" (Terr. Mag., Vol. II, p. 21); (3) furthermore, Schuster remarks (Terr. Mag., Vol. I, p. 16):

If we could adopt Dr. Schmidt's numbers as final, they would show that the outside magnetic potential is displaced toward the east. Such an effect might be produced by currents induced in a medium rotating more rapidly than the earth, which might be the case if the upper currents of the atmosphere had a general drift from west to east. The displacement of the outside potential, according to Dr. Schmidt, is, however, greater than 90°, which is difficult to reconcile with the hypothesis of induced currents under any circumstances.

Dr. von Bezold attempted to analyze the earth's magnetic potential as a sine distribution about the axis of rotation. (Sitz.-Ber. Berlin, 1895, p. 363.) Dr. Schmidt concludes his examination of this question of distribution relatively to the rotational and other axes: "No argument favorable to the assumption can be drawn that the principal part of the terrestrial magnetic force stands in any relation to the rotation of the earth." (Terr. Mag., Vol. I, p. 27.)

V. Carlheim-Gyllensköld makes the following remarks regarding the origin of the disturbing forces in his paper "L'attraction magnétique de la terre," 1896:

Any complete theory of the magnetic attraction of the earth appears to be possible only on the condition that the observed effects result from a cause acting regularly

and continuously in the same manner (p. 29). In our view, the phenomenon of the secular variations of the magnetization of the earth is a great phenomenon of electromagnetic induction operating in the rarefied layers of the atmosphere, put in motion by the rotation of the earth (p. 32). If the relative movement of the upper layers of the atmosphere is directed in the opposite sense to the diurnal motion, the observed movements of β_n^1 conform to the theory.

It is, however, a well-known meteorological fact that the relative motions of the upper atmosphere are all eastward and not westward, as required by Gyllensköld's view.

In a more recent paper (*Zur Theorie des Erdmagnetismus*, 1897) von Bezold integrates through several circuits on the surface of the earth for vertical currents, and concludes that the errors of observation are such that the material affords only indecisive results (p. 5); that the great ocean areas preclude observations to such an extent as to invalidate the application of the method to a circle of latitude (p. 6); that when applied to small, well-surveyed circuits the departure of the sum from 0 is well within the limits of error of observation, being about 1 per cent (pp. 8, 9); but that further extension of the theorem to small areas is to be encouraged. Regarding the Schuster horizontal currents, von Bezold finds some resemblance between the magnetic and the meteorological diurnal variations, but sees a difficulty in the fact that Schuster's currents require one cyclone and one anticyclone in each hemisphere, while the conditions of solar radiation would give only one of each kind for the northern and the southern hemispheres combined.

Quite recently (1897) Dr. H. Fritsche has recomputed the Gaussian Constants to terms of the sixth order, depending upon the Neumayer Charts, 1885.0, beyond which development it is shown to be analytically disadvantageous to go. The outcome is a decided improvement in the representation of the distribution of the earth's magnetism for that epoch, but the question of the causes of the variations and the disturbances is not considered.

This brief summary of the latest investigations of the causes of the disturbances of the needle indicates that while the theory of atmospheric electric currents is the favorite one, yet the effort to employ it leads to uncertain and even contradictory conclusions. Having thus reviewed the status of the problem, we proceed to an exposition of the arguments in favor of the alternate hypothesis of the earth immersed in two external solar magnetic fields.

GENERAL NATURE OF THE PROBLEM.

In the papers¹ already published such considerations and conclusions have been reported regarding this solar-terrestrial problem as seemed justified by the developments secured. While indicating progress in

¹Amer. Journ. Sci., Nov., 1890; July, 1891; Sept., 1891; Dec., 1894; Aug., 1895. Astron. and Astro. Phys., Feb., 1893; Oct., 1893; Nov., 1893; Jan., 1894. Astr. Soc. Pac., No. 14, 1891; No. 16, 1891. Amer. Metl. Journ., Jan., 1892; Sept., 1893; Jan., 1894; Jan., 1895. Smithsonian Instn. Monograph, Oct., 1889. Weather Bureau Bulletin, No. 2, 1892; No. 20, 1896. Science, Oct. 18, 1895; July 17, 1896.

the research, they were lacking in completeness for two reasons: First, because the bulkiness of the details of computation precluded a sufficient reproduction of the data upon which conclusions were based to satisfy the reader; and second, because the statements of subordinate parts could not be made in reference to the general result, since the final solution of the problem had not yet been attained. The difficulty of presenting the computation remains, but an effort will be made to furnish such specimens of it as will permit an accurate inference regarding the character of the data, especially in the critical parts of the work. This particularly applies to the period of the solar rotation, the discussion of the normal solar curve, the law of the inversion of the same, and origin of the great magnetic disturbances. It is likewise believed that a clear conception of the general problem in relation to its parts has been secured, so that the descriptions will be now more definite. The discovery of the phenomenon of inversion of the solar curve threw the research into confusion, and as long as a rational explanation of it was wanting, progress was naturally much impeded. This difficulty has, however, yielded and disclosed a law in harmony with the antecedent analysis, such that it not only confirms previous results, but furnishes a delicate test of the fact of the direct action of the sun as a magnet upon the earth.

The greatest obstacle in the way of conducting this research to a conclusion consists in the *looseness* that pervades the entire series of solar and terrestrial observations. This is not due to the instrumental inaccuracies, but inheres in the nature of the physical forces to be measured. The great distance of the earth from the sun of course reduces the magnetic force to a very small quantity; the variability of the solar output, including small abnormalities and great perturbations, serves to mask its normal field; the interaction of two magnetic fields, having regard to the aspects of the sun and the earth in their orbital revolution, introduces a curious system of effects on the instruments at our stations; the measurement of the transformed magnetic energy contained in the meteorological elements is seriously impeded by the strong convectional currents of the ordinary circulation of the atmosphere. In laying out the policy to be pursued in conducting the investigation it was decided to rely upon a very large exhibit of observations rather than upon any theory regarding them, and accordingly the entire mass of magnetic and meteorological data available has been examined for this purpose. It has now become easy to perceive continuous symptoms of the action of the solar forces after having ascertained the laws that govern them, but a full verification of the work by others will involve an extensive use of the same observations.

In order to facilitate the description of the solution of the problem, a free allusion will be made to the following conclusions, which form the main features in the solar-terrestrial problem:

1. The sun emits two magnetic fields of force:
 - (1) The electro-magnetic, in radial vibrations.

(2) The polar, in curved lines of convergence.

2. These fields are each distorted in the neighborhood of the earth, as if it were a shell of permeable material, one-fifth the radius in thickness, placed in the paths of the undisturbed lines.

3. The force of the normal polar field of the sun is at the distance of the earth represented by a periodic curve, the synodic period being 26.68 days.

4. This normal type curve undergoes inversion in a semiannual period, and is a simple effect within the terrestrial magnetic field, due to the orbital aspects of the earth and the sun, as regards their magnetic lines.

5. The same typical normal curve exists in the atmospheric pressures and temperatures, especially of the west Canadian Provinces, together with the synchronous inversion.

6. The effect upon the general circulation of the currents of air is to facilitate the formation of highs and lows in a sequence prompted by the solar magnetic forces.

7. This leads to a theory of atmospheric circulation differing considerably from Ferrel's and from Hann's well-known views, but embodying the important facts of each, together with certain additional features.

SUMMARY OF THE RESULTS OF PREVIOUS RESEARCHES.

Current scientific opinion regarding the reach of the sun's magnetic field, if it exists, into space so far as to embrace the earth has unfortunately been molded into an attitude on the whole unfavorable to accepting the view just outlined. This impression, however, may properly be revised, in view of the great progress that has been made toward a fair understanding of the properties of the interstellar medium. Electromagnetic radiation requires an ether of enormous intrinsic potential power, and cosmical space is no longer to be conceived as filled with a thin or vacuous substance; matter is the product of the ether, rather than indifferent to it; to supplement these views, a polar system of magnetic force should now be added, having the sun as its seat of magnetization. Polarization, displacement, charge, number of lines of force per unit volume, are varying expressions for one fundamental property. The static and dynamic states have less need to stand over against each other as distinct ideas, just as potential and kinetic energy show a decided tendency to be merged into one; it is quite probable that dynamic concepts will finally absorb the static and potential, as merely limiting cases in the analysis. If it is proven that the sun sustains static polar magnetic lines, which are traversed by occasional transient, variable, currents, as well as the radiating shells of electro-magnetic energy, to the distance of the earth, then this must be an important factor in the final solution of the problems of the ether, and the nature of electricity and magnetism.

More especially, the objections to making the sun the seat of a field of polar magnetic force have been threefold, as stated above. (1) "If

the sun were a saturated steel magnet, end on to the earth and then reversed, the needle would be deflected only 10' in arc." The substance of this argument has been repeated in many forms during the past fifty years. Admitting its truth, it does not exclude smaller deflections in the earth's magnetic field from being referred to such solar action. The indications are that certain variations of the needle depend upon a solar field, sustained by a magnetization usually less than saturated steel, and rising above it only temporarily, in great disturbances. (2) "Since an induced steel magnet loses its magnetization on increasing the temperature above a certain degree, the high temperature of the sun renders its own magnetization improbable." This argument proceeds on the assumption of an extrapolation of certain physical properties of matter, but it may or may not be true. It is offset by two leading facts: First, the earth is at high temperatures in the interior, far above the critical temperature of the steel in question, and yet it sustains a permanent magnetic field, so that a steel magnet is not the true analogue to the sun, but rather the earth itself. Second, a careful discussion of the curvatures of the lines visible at eclipses within the solar corona, shows that the system can be well accounted for by referring it to the equation of the lines of force surrounding a spherical magnet, the lines being seen in projection. (3) "The amount of work done in sending out the magnetic waves observed in great disturbances can not conceivably be attributed to any dynamical action within the sun." But if it is shown that certain moderate variations of the earth's field do come from external sources, by inference the sun, then in the account of the unusual disturbances, two courses are open: (1) By the discussion of the deflecting forces to prove that the energy does come from outside the earth, in accordance with which result the physical laws must be interpreted; (2) or else from the inside, in which case the causes of the perturbation of the earth's permanent magnetism must be investigated. The physical properties of the interior of the sun or the earth, as the case may be, can be studied as the results depending upon these deflecting forces indicate, but the whole subject being a mere question of fact, no hypothesis should form a barrier to an impartial investigation of the forces themselves, and all the consequences flowing from them. It may be concluded that it is "a perfectly proper object for investigation to find whether there is, or is not, any disturbance of terrestrial magnetism, such as might be produced by a [constant] magnet in the sun's place." (Kelvin, *Nature*, Vol. XLVII, p. 108.)

The positive testimony in favor of the direct magnetic action of the sun upon the earth is abundant, and on the whole powerful. It is summarized as follows: (1) The inclination and the intensity of the earth's magnetic field in all latitudes increases as the earth approaches the sun in its orbit; (2) all the magnetic elements undergo variation in the period of the solar rotation; (3) all the magnetic elements pass through secular variations in the 11-year period, synchronously with

the frequency of the sun spots, prominences, faculae, and coronal extension; (4) the aurora, the earth currents, the atmospheric temperatures, pressures, the rainfall, the latitude of the mean storm tracks, the velocity of the eastward drift, suffer changes synchronous with the annual period, the solar rotation period, and the 11-year period; (5) the immediate connection between individual sun spots and terrestrial magnetic and atmospheric storms has not been clearly demonstrated, but there are several observations showing that abnormal agitations affect the sun and the earth as a whole and at the same time.

METHOD OF COMPUTING THE MAGNETIC OBSERVATIONS.

The study of the magnetic observations themselves involves the disentangling of the several periods, diurnal, solar rotation, annual, and 11-year. The first point to settle is the determination of what is to be taken as the earth's normal field, added to which the variations impressed at any given instant produce the actual field as observed. This involves the question of quiet days and large disturbances, in forming the monthly and annual means. My conclusion is as follows: (1) the so-called "quiet" day means merely that the trace is smooth—that is to say, not broken up with rough oscillations having wide amplitudes, but yet balanced on either side of a mean. This, however, is no criterion in itself whether the trace of a quiet day lies on the true secular normal of the element or not, and it is easy to see by inspection of the curves observed from day to day that a quiet trace is often depressed or elevated as a whole, relatively to the base line, compared with neighboring days, throughout its 24-hour extent. This swaying up and down of quiet traces throughout many millimeters seems to be fatal to the practice of taking the mean of quiet days by themselves as the true normal, inasmuch as many days of moderate oscillation are thus without reason excluded from the series of days upon which the mean depends. On the other hand the case is very different with the great disturbances, because these are not well balanced, but almost always show a large distortion, on one side of the mean of the element. Thus in the horizontal force the disturbances of pronounced type almost invariably diminish the absolute value of it for the 24-hour means. Hence, to include them in the normal would be to depress it to such an extent as to shift the mean on one side of its true position, and thus introduce a constant error into the system of deflecting forces. A comparatively wide oscillation of the component of the horizontal deflecting force σ amounts to about 0.000250 C. G. S., and this may occur without any unusual perturbation of the field. It is, on the other hand, equally erroneous to omit these disturbed days entirely from the mean, and I have compromised the matter by counting every disturbance above the limit just indicated as that value itself. Thus -0.000645 would be summed in the means as -0.000250 . This is arbitrary, but it certainly saves an unnecessary distortion of the normal field. Hence

the rule becomes: "Diminish all disturbances to the limit 0.000250 and then take the mean of all the days of the month, this mean being the value of the normal field for the fifteenth day of the month; interpolate proportionally between the fifteenth days of successive months for the values of the normal on the several intermediate days; subtract the normal value for the day thus obtained from the observed value of the day, and the difference is the rectangular component in that element, horizontal force, declination, or vertical force ($\Delta H, \Delta D, \Delta V$), of the deflecting vector; reduce the number thus obtained to equivalent C. G. S., units (dx, dy, dz), and transform the same to the polar coordinates of the vector (σ, s, α, β); this is the vector of the deflecting force, impressed for the twenty-four hours upon the normal field at the station, to produce the observed force; s is the total vector acting in a plane having the azimuth β , counted N. W. S. E. from the magnetic meridian of the station; the vector is inclined at the angle α to the horizontal plane, and it is taken positive below σ , which is the component of s on the horizontal plane." In case the deflecting vector is required for a certain hour within the twenty-four hours composing the given day, the mean diurnal variation for that hour must be added to the interpolated normal mean, and this value for the hour is to be subtracted from the observed value to obtain the component of the element at that hour. In discussing disturbances it is necessary to take this step carefully, and not to omit it from the computation. In the course of the computations for the years 1878-1893, inclusive, I reduced 105 dates from some larger number to 0.000250 C. G. S.; half of them were small changes and the remainder large, thus making important changes in about *one per cent* of the dates. This method therefore makes use of all the given observations, except the extreme disturbances, in obtaining the mean value for the fifteenth day of each month, thus locating twelve points on the secular curve for the year, and assuming that the secular variations in the terrestrial elements progress uniformly from point to point. The method works well practically, and it seems to reduce the necessary assumptions to a minimum (Compare Bulletin No. 2, U. S. Weather Bureau, 1892, for details).

The vector systems of deflecting forces obtained in this way from the available published reports of magnetic observations, covering the years 1841 to 1895, inclusive, have been made the basis of the investigation. The labor consisted in making these simple transformations, but it is seen that no theoretical bias of any kind has been imposed upon the actual facts. The inferences obtained grow naturally out of the resulting systems of vectors of deflecting forces, after they are marshaled in array as determined by observations. For the greater part, this bulletin will be concerned with the vectors depending upon the 24-hour means, from which is to be derived the period of solar rotation and the characteristics of the solar magnetic field. This 24-hour vector system is evidently secured by confining the computation to the

columns "mean of 24 hours." If the hourly vectors are required, the work is limited to the "hourly means" for each month; if the hourly vectors for large disturbances are wanted, the two systems must be combined as mentioned above. All three of these processes have been executed with interesting results which it is proposed to enumerate, though the first will cover more ground than the others.

DIFFICULTY OF FINDING THE ROTATION PERIOD OF THE SUN.

Many attempts to find the true period of the solar rotation have been made by others, the investigations covering a half century, but the outcome is exceedingly unsatisfactory as regards a definite result. The attack has been made along three lines: (1) the rotation period of the sun spots, (2) the periodic variation of the terrestrial magnetic and meteorological elements, (3) the displacement of the lines in the solar spectrum. The outcome shows that the constituents of the sun have periods of rotation differing both in latitude and altitude, indicating some type of circulation not wholly unlike that of the currents in the earth's atmosphere. The law of the rotational periods in the several latitudes is quite easily and accurately determined where spots are visible, but the laws of extrapolation to latitudes outside the spot belts are not in agreement for the different authors.

TABLE I.—*Siderial and synodic periods of the rotation of the sun.*

[Compiled from Repertorium der Physik, p. 626, 1886, and other sources.]

Author.	From—	Siderial.	Synodic.
Faye	Carrington's observations	25. 18	27. 06
Spörer	Spörer's	24. 55	26. 32
Broun	Makerstown, 1844-45	24. 20	25. 92
Do	Greenwich, 1850-51-68-70	24. 15	25. 86
Hornstein	Prague, 1870	24. 87	26. 60
Do	Wien, 1870	24. 61	26. 39
Do	Inclination, Vienna, 1870	24. 30	26. 03
Do	St. Petersburg, 1870	24. 48	26. 24
Liznar	E. disturbances, Vienna, 1882-3	24. 32	26. 05
Do	W. disturbances, Vienna, 1882-3	24. 24	25. 96
Müller	All disturbances, Pawlowsk, 1882-3	24. 03	25. 66
Do	Horizontal intensity	24. 09	25. 70
Do	Vertical intensity	24. 15	25. 86
Do	W. disturbances in declination	24. 16	25. 87
Do	E. disturbances in declination	23. 81	25. 47
Do	Daily variation of barometer—		
Hornstein	Prag, 1870	24. 12	25. 82
Broun	Singapore, 1841-45	24. 13	25. 83
Bigelow	European magnetic field, 1878-1889	24. 86	26. 68
Do	Also extended, 1841-1897	24. 86	26. 68
Delambre	Sun spot observations	25. 01	26. 85
Spörer	do	25. 23	27. 10
Schneider	do	25. 33	27. 22
Langier	do	25. 34	27. 23
Carrington	do	25. 38	27. 27
De la Landé	do	25. 42	27. 32
Cassini	do	25. 58	27. 51

TABLE I.—*Sidereal and synodic periods of the rotation of the sun*—Continued.

ANGULAR ROTATION OF THE SUN SPOTS IN SEVERAL LATITUDES.

[Expressed in minutes of arc for the daily sidereal motion.]

Latitude.	Carrington.	Spörer.	Faye.	Tisserand.	Bigelow.
Equator	867	881	863	858	868.7
5°	864	882	863	858	868.7
9°	858	854	863	858	868.7
12°	854	^a 852	863	858	868.7
14°	850	844	863	858	868.7
18°	842	838	863	858	868.7
21°	837	832	863	858	868.7
25°	830	827	863	858	868.7
30°	818	824	863	858	868.7

^a Equivalent to 25.35 sidereal, 27.24 synodic.

Table 1 shows the periods of rotation determined in several investigations and the mean daily motion of the spots in different latitudes. The mean synodic rotation of the total number of sun spots is 27.25 days, approximately, and it is the drift in solar mean latitude $\pm 12^\circ$. This value has been widely adopted as the period of solar rotation, but it is extremely difficult to see any reason why such an average motion, the mean of very different values in angular velocity, should be the true period of the solar nucleus itself. For sun-spot observations it may be useful, but certainly there is need of its further indorsement to make it applicable to the body of the sun as a whole. On the other hand, examination of the terrestrial data shows that there is a tendency to obtain periods lower than the mean number, 26.70 days, as the effective period of solar rotation at the distance of the earth. The separate determinations differ seriously among themselves, and tend to discredit one another, so that little weight has been given by astronomers to this set of results, perhaps less than they deserve. The spectroscopic work, though important, has not reached a conclusion, and can be regarded as only in its formative stage, though likely to produce decisive evidence in the end. As matters stand, the contest seems to have narrowed down to an assignment of 27.25 days or 26.70 days as the approximate period of synodic rotation of the sun, the former being the mean rotation of the spots in latitude $\pm 12^\circ$, and the latter that at the equator, as determined by the visible angular motion of the sun's surface and the terrestrial variations respectively.

It is proper to inquire why the terrestrial data should give such loose results. There are probably three reasons for this: (1) the observations give the data in a very complex form, composed of several interacting systems; (2) the series of observations used has been comparatively short, too brief to afford clear residuals after the wasteful process of balancing out local forces from other impressed sources of energy; (3) the employment of the Gaussian principle of the "sum of the squares of the residuals a minimum." The third needs further explanation. Having a series of residuals, the assignment of $(n-1)$ (n)

($n+1$) days as the period successively for the determination of n is proper under certain conditions, especially whenever a simple mean period is to be obtained—that is, for example, when the resulting curve is a simple harmonic function. But in the case of several overlapping functions it will not work, especially with a short series; and in case of an inversion of the periodic curve it will fail entirely. The fact that so many researches with this method have been indecisive induced me to believe that either one or both of these conditions were at the basis of the difficulty, and accordingly in planning this investigation the Gaussian method was excluded from the trial. The outcome shows that the inversion of the curve is the real cause of the failure of the method; the fact that the curve has many maxima in a period, but is not compounded of overlapping periods, not being the barrier to its employment. It will be shown later that inversion takes place on the average on February 1, April 20, July 15, October 15 of each year, so that unless the observations of a year were subdivided into the proper parts, the period would emerge only feebly from the observations.

NOMENCLATURE, DEFINITIONS, AND TYPE MAGNETIC FORCE DIAGRAMS.

For the sake of assisting those readers who are not familiar with the language used in the science of terrestrial magnetism, the following summary of its leading terms is reproduced from Bulletin No. 20, United States Weather Bureau, 1897, on Storms, Storm Tracks, and Weather Forecasting. The nomenclature grew up in consideration of the behavior of a magnet freely suspended in the earth's magnetic field, rather than with regard to the wider aspects of science that have since been developed, and hence the choice of reference directions on the surface of the earth is of a practical character, but not the best that might have been selected. Since the earth is positively magnetized in its southern hemisphere, in the northern hemisphere a freely suspended needle dips with its north-seeking end beneath the horizon, and inclines to the west of the geographical meridians, taken as a whole over Europe, where the science was first studied. This needle will hang tangent to the line of force determined by the earth as a magnet at the station considered, and there have consequently been employed two systems of coordinates to define the force of the magnetic field at the point of suspension.

(1) The first system of coordinates is—

F , the *intensity* of the magnetic force of the earth.

D , the *declination*, positive west from geographical north.

I , the *inclination*, positive below the horizon.

These give the exact direction and magnitude of the magnetic force.

(2) The secondary system of coordinates is—

H , the *horizontal component*, positive north along the magnetic meridian.

D, the *angular declination*, positive west.

V, the *vertical component*, positive downward.

These also determine the *vector*—that is, direction and magnitude—of the magnetic force.

If the earth's magnetic field were permanent, these values of F D I or H D V would be constant at every station on the globe. But they are all continually fluctuating in several periods—the diurnal, the solar, the annual, and the secular.

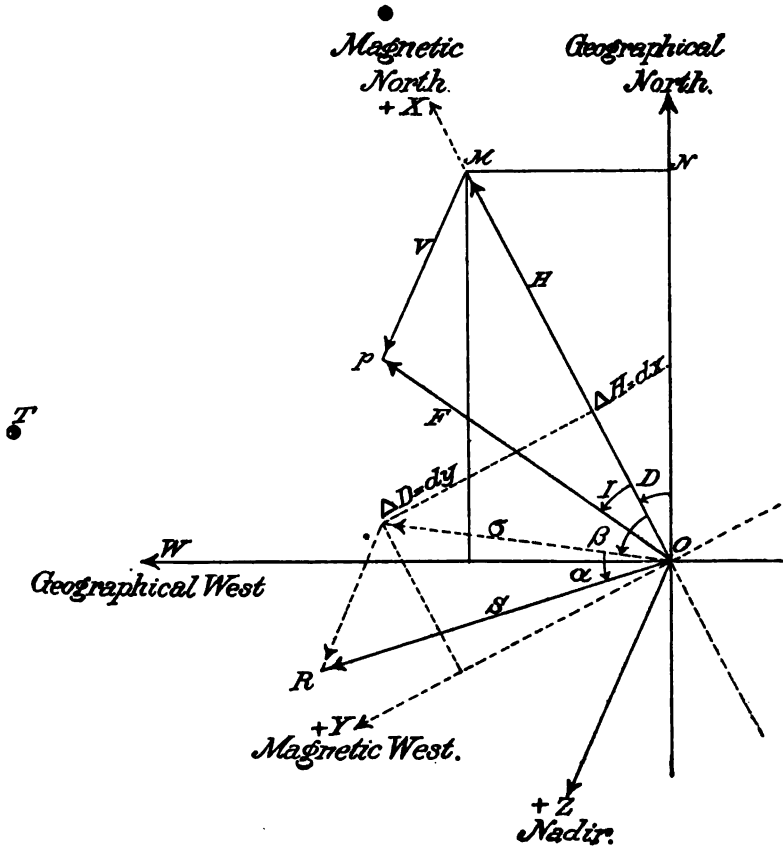


CHART 1.—Coordinates of normal and deflecting magnetic forces.

The *diurnal period*, twenty-four hours, is due to the rotation of the earth on its axis, changing the components of the earth's normal field in relation to the external magnetic lines of the force in the ether as induced by solar action.

The *solar period*, 26.68 days, is due to the rotation of the sun on its axis, carrying with it the *coronal* magnetic field, which it continuously sustains, with an intensity varying along the solar meridians, and also as a whole in the solar 11-year period.

The *annual period*, 365.25 days, is due to the earth's motion about the

sun in its orbit, which changes the aspect of the sun's magnetic system relatively to that of the earth, as the sun moves in declination with the seasons.

The *secular periods* are but little understood, but there are several of them: (1) The 11-year period, due to the slow workings of magnetic masses within the solar nucleus; (2) the longer periods of five hundred to three thousand years, differing in the several parts of the earth, and due to the slow redistribution of magnetism within the earth, and (3) the very long secular periods of the sun as a variable star by which the terrestrial system must be affected, just as it is in the shorter periods.

To study the causes that modify the earth's normal magnetic field in these several periods it is necessary to disentangle the superposed forces from the normal field, in order to have the components of the *deflecting forces* at any time. The simplest way of doing this in practical work is to take the magnetic meridian at a station as the plane of reference with—

X, positive to the magnetic north.

Y, positive to the magnetic west.

Z, positive to the magnetic nadir.

Hence, *variations* in the horizontal force ΔH , in the declination ΔD , in the vertical force ΔV , may be combined into a horizontal component σ , which makes an angle β on the horizon plane with the magnetic north, and also into a total vector force s which makes a vertical angle α with σ , and an angle β between its plane and that of the magnetic meridian. In Chart —

O N is geographically north, O W west, O Z nadir.

O P = F, N O M = D, M O P = I. First system.

O M = H, N O M = D, M P = V. Second system.

σ is the resultant of $\Delta H = dx$ and $\Delta D = dy$, and makes the angle $\beta = \Delta H. O. \Delta D$ with the magnetic meridian.

s is the resultant of σ and $\Delta V = dz$ and makes the angle $\sigma = \Delta D. O R$ with σ . The vector sum of O P and O R is O T, and therefore O T gives the direction of the needle and the intensity of the magnetic force at the time considered.

For many years it has been known that there must be a close physical connection between the sun and the earth because of the definite fluctuations in intensity between solar and terrestrial phenomena. Our investigation of this subject has shown that the transference of energy is not only along the ecliptic, but also in widespreading lines which are perpendicular to the ecliptic at the earth, this circumstance indicating that the sun, as well as the earth, is an immense spherical magnet. The sun therefore emits energy along two paths to the earth and in two different forms of radiation: (1) Along the ecliptic, in *electromagnetic waves*, wherein the vibration is in planes perpendicular to the line of propagation; (2) in *magnetic curves*, wherein the ether motion is prob-

ably rotatory, which is called the *coronal* field because of the intimate relation of the lines of the solar corona to magnetic lines of force.

The term *electromagnetic*, in this connection, is descriptive of the Maxwellian theory of light, which makes it a true radiation of energy in straight lines from its source. It is analyzed into a wave of electric force, plus a wave of magnetic induction, these forces being at right angles to each other in the plane wave front, the component waves being in quadrature along the path of propagation. The immense rapidity of the vibrations of light, in the case of a train of waves from the source to the observer, practically integrates the system into a type of polarized ether.

The magnetic curves which join the opposite polarities of a permanent magnet have an entirely different nature, but it is not definitely known what the state of the ether is when it sustains them, though probably they are simply rotational ether vortices having their ends on the magnetized matter. As the form of these curves, and the mode of combining systems of magnetic forces should be kept clearly in mind, the following diagrams are added:

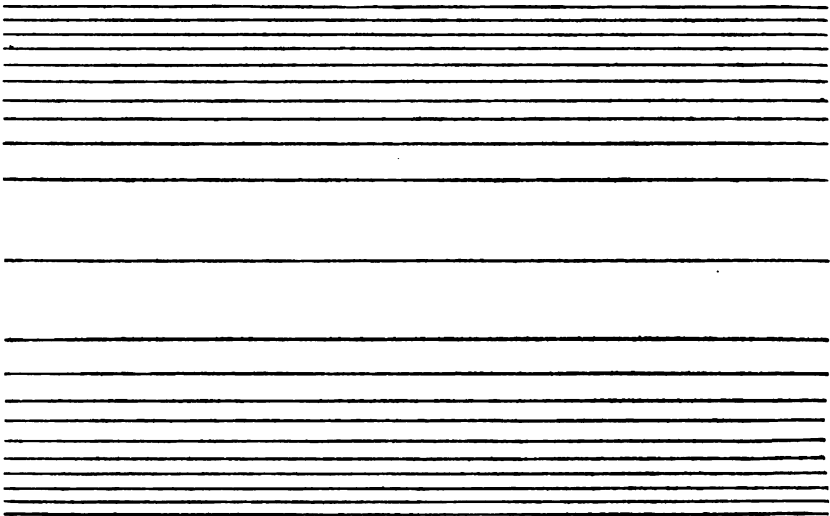


CHART 2.—Uniform field.

$$r_n = \sqrt{\frac{n}{\pi \cdot H}} \quad H = 0.001273 \frac{\text{Gt}}{\text{Cts}}$$

With a given value of H compute the distance r_n from the axis of the field for any line n .

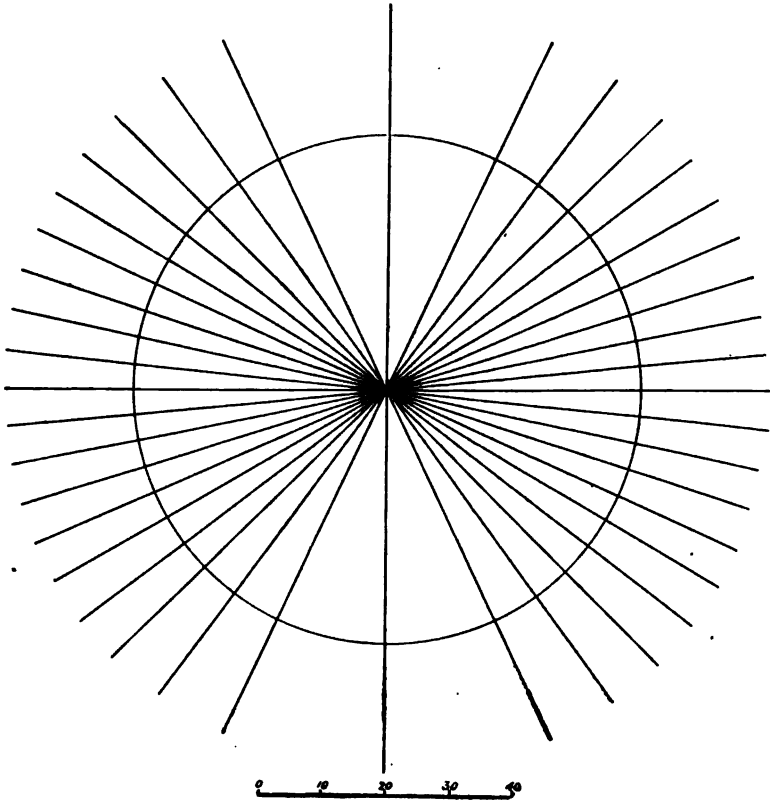


CHART 3.—Unipolar field.

$$F = 4\pi m = 20$$

$$m = 1.592 \frac{C^2 G^{\frac{1}{2}}}{S}$$

Subdivide the diameter into $4\pi m$ equal parts, draw parallel chords through the division points at right angles to the axis, and a series of radii to the points of intersection on the circle.

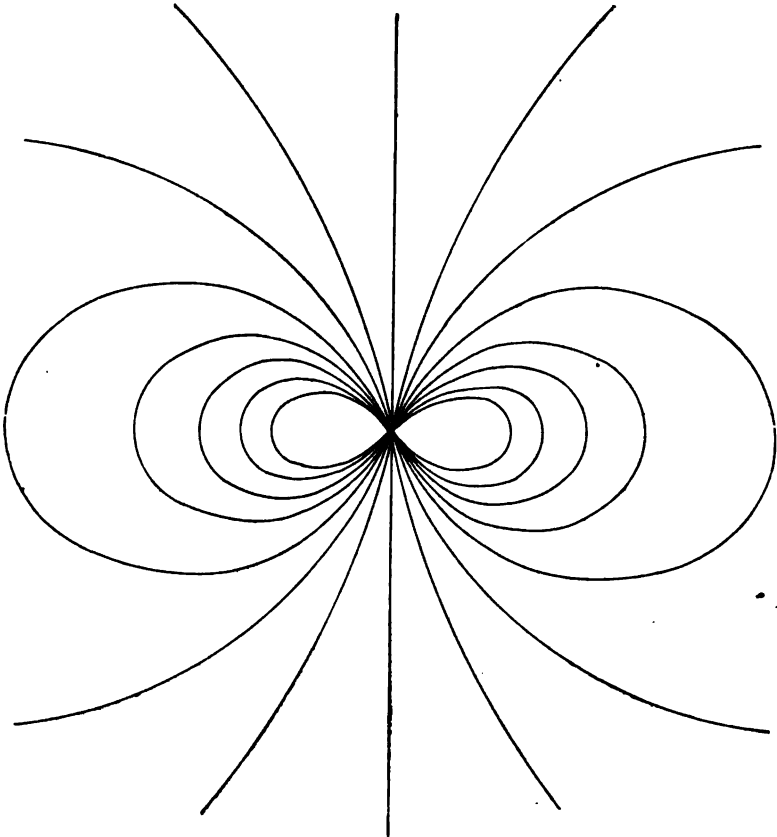


CHART 4.—Bipolar field or doublet.

$$\pm m = \pm 1.592 \frac{C^2 G^{\frac{1}{2}}}{S}$$

Place two unipolar fields near the same center and draw resultant curves through the points of intersection. Or else compute the curves from $N = C \cdot \frac{\sin^2 \theta}{r}$, where C may be taken equal to unity.

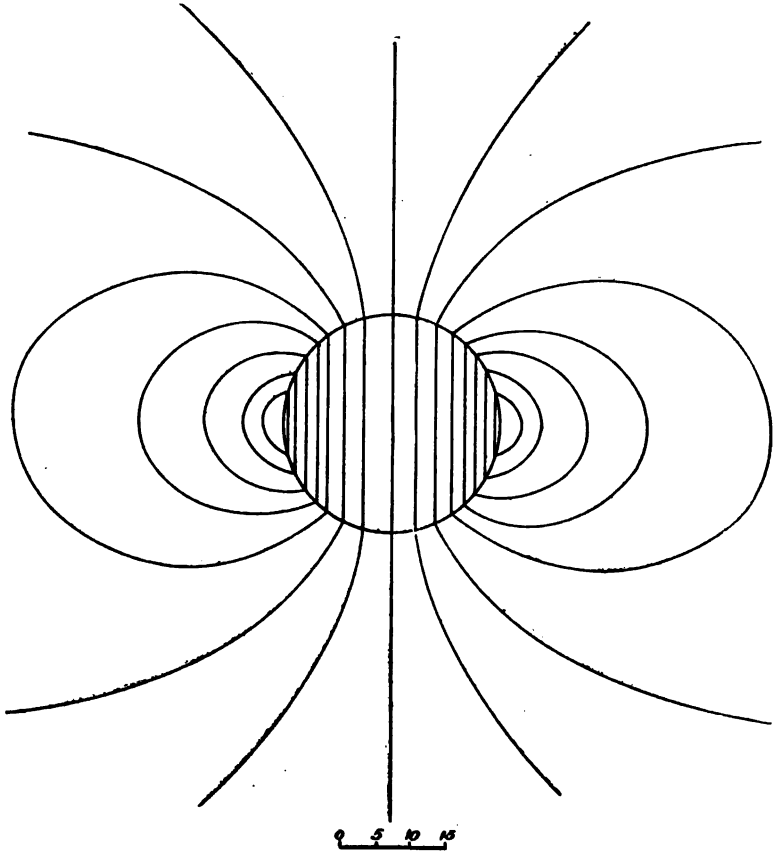


CHART 5.— Uniformly polarized sphere.

This is the same as a bipolar field outside the sphere, and a uniform field inside, connecting discontinuously at the surface.

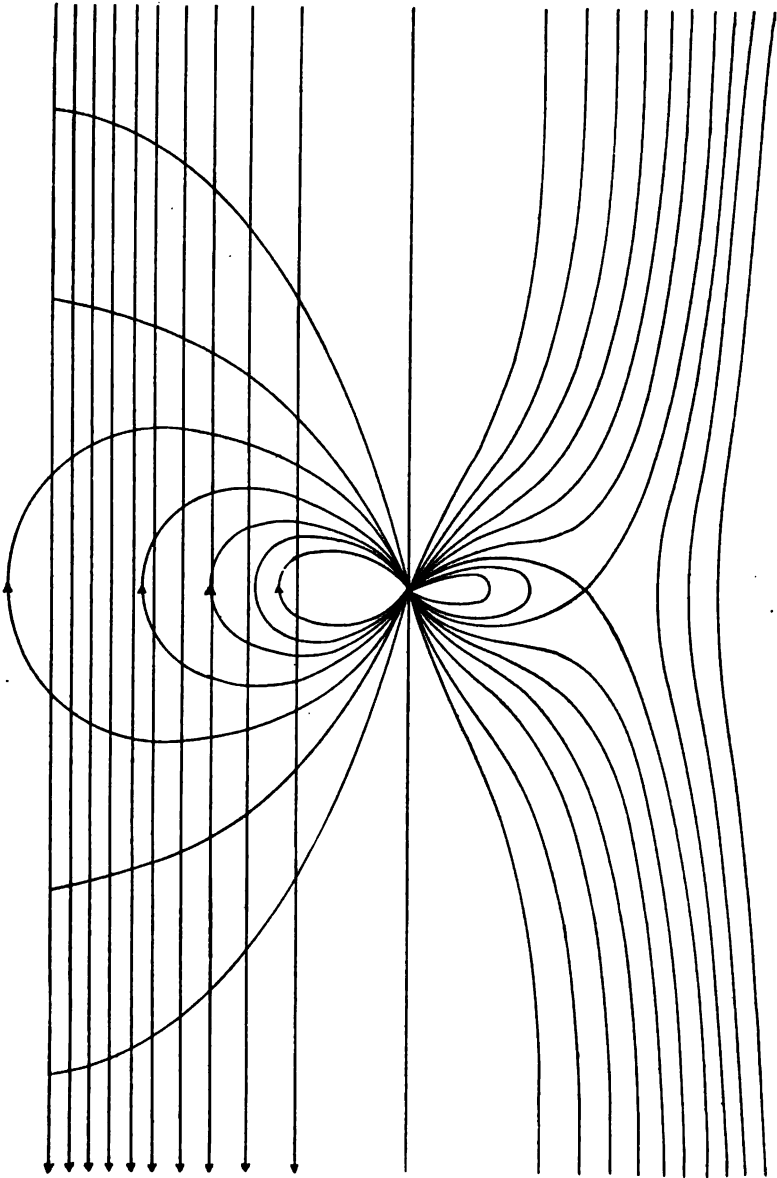


CHART 6.—Doublet in a uniform field.

Stable position. Components on the left side; resultant on the right side.

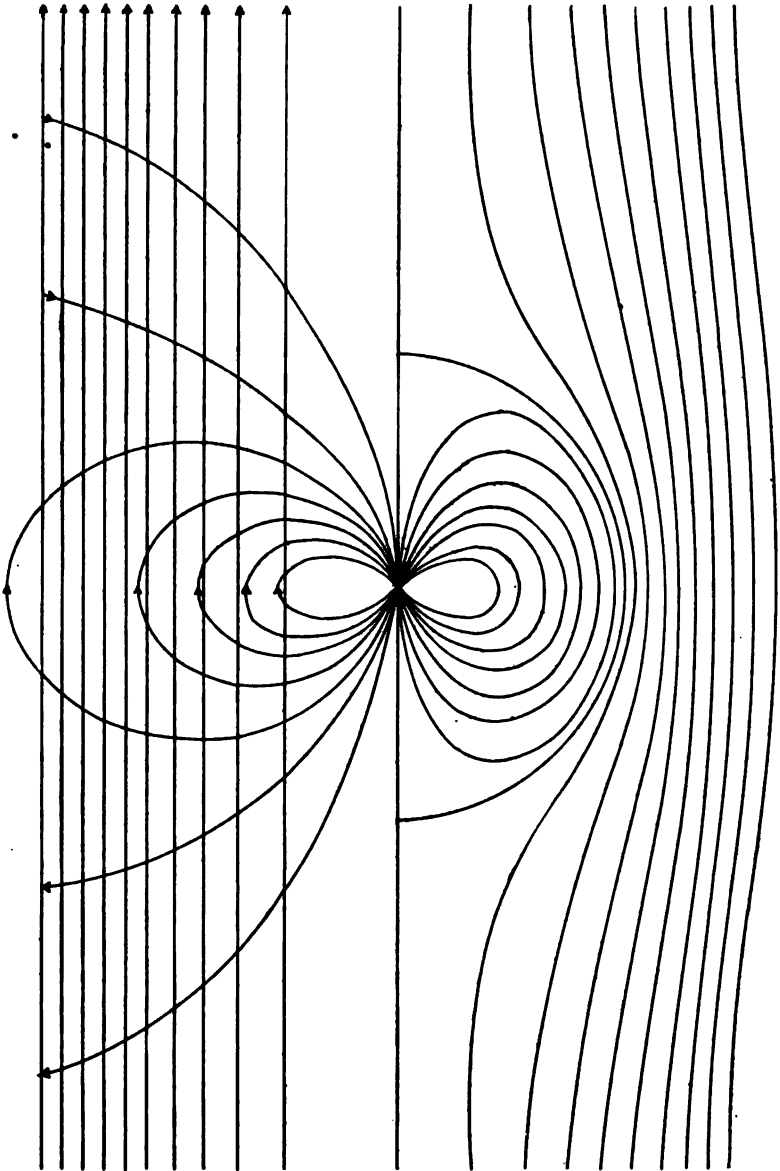


CHART 7.—Doublet in a uniform field.

Unstable position. Components on the left side; resultant on the right side.

The method of procedure decided upon was to spread out the polar coordinates of the deflecting forces impressed upon the normal terrestrial field, in long tables, and to discover by inspection the fact of periodicity if it existed. This has been a very laborious procedure, as the transformations above described cover the years 1878–1889 inclusive, for five to eleven stations. The result was announced at the Chicago Congress, 1893; but the possibility of having merely added one more to the long list of approximate periods already published, caused me to withhold the details of the computation till practical experience with its efficiency had given at least some conclusions calculated to fortify its validity. The work can be only illustrated in this bulletin, but the example given is a fair specimen of the remainder of this kind of computation.

The components are arranged in the order H. D. V., representing the development X. Y. Z.; H. D. V. are taken from the reports of observations, and are the absolute values corrected for temperature and instrumental peculiarities; H_0 , D_0 , V_0 are the adopted secular normal values of the components, assuming that the mean for the month is true for the 15th day, and that the variation is proportional to the time between the successive values thus determined; dx , dy , dz are the corresponding rectangular coordinates reduced to units of the sixth decimal C. G. S.

(0.000001 dyne): $\sigma = \sqrt{x^2 + y^2}$, $s = \sqrt{dx^2 + dy^2 + dz^2}$, $\tan \beta = \frac{dy}{dx}$, $\tan \alpha = \frac{dz}{\sigma}$;

β is positive from the north magnetic point through the *west*; α is positive below the horizon.

In the volume of magnetical and meteorological observations, Greenwich, March, 1887, H is found in column 7, p. (iii); D in column 4, p. (ii); V in column 7, p. (vi); the precepts for conversion of the values into C. G. S. units occur at the top of the several pages.

$$H - H_0 = \Delta H, \quad D - D_0 = \Delta D, \quad V - V_0 = \Delta V,$$

$$1 \text{ unit } \Delta H = 0.0000018 \text{ C. G. S.}$$

$$1 \text{ unit } \Delta V = 0.0000044 \text{ C. G. S.}$$

$$1 \text{ minute arc } \Delta D = 0.0000530 \text{ C. G. S., where } dy = H_0 \tan \Delta D.$$

The table of transformations is appended; H. D. V. are copied from the report; H_0 , D_0 , V_0 are interpolated from the monthly means; ΔH , ΔD , ΔV are reduced to dx , dy , dz , in units sixth decimal C. G. S; σ , s , α , β are the equivalent polar coordinates.

TABLE 2.—*The mean deflecting forces in rectangular and polar coordinates.*

[Greenwich, March, 1887.]

	H	H ₀	ΔH	D	D ₀	ΔD	V	V ₀	ΔV	dx	dy	dz	σ	s	α	β
1	464	477	-13	52.7	51.65	+1.05	497	483	+14	-23	+56	+62	60	86	+46	112
2	477	477	0	52.2	51.65	+ .55	497	481	+16	0	+29	+70	29	76	+67	90
3	501	478	+23	52.0	51.65	+ .35	474	479	-5	+41	+18	-22	44	49	-26	25
4	499	478	+21	52.0	51.66	+ .34	478	476	+2	+38	+18	+9	42	43	+13	26
5	480	478	+2	51.7	51.66	+ .04	486	472	+14	+4	+2	+62	5	62	+66	27
6	418	479	-61	50.8	51.66	- .86	487	470	+17	-110	-46	+75	119	141	+32	203
7	429	479	-50	51.5	51.67	- .17	489	468	+21	-90	-9	+92	91	129	+45	186
8	431	480	-49	51.8	51.67	+ .13	479	465	+14	-88	+7	+62	88	108	+35	174
9	401	480	-79	51.4	51.67	- .27	485	463	+22	-142	-14	+97	143	173	+34	185
10	469	480	-11	52.1	51.68	+ .42	462	461	+1	-20	+22	+4	29	30	+10	133
11	450	481	-31	51.5	51.68	- .18	467	459	+8	-56	-10	+85	57	68	+80	190
12	451	481	-30	51.8	51.69	+ .11	468	456	+12	-54	+6	+53	55	77	+44	172
13	442	482	-40	51.6	51.69	- .09	469	454	+15	-72	-5	+66	72	97	+42	183
14	448	482	-34	52.2	51.70	+ .50	454	452	+2	-61	+27	+9	67	68	+7	156
15	456	483	-27	51.7	51.70	- .00	433	449	-16	-49	0	70	49	86	-55	180
16	404	484	-80	51.2	51.67	- .47	437	448	-11	-144	-25	-48	147	156	-18	190
17	458	485	-27	51.6	51.64	- .04	437	448	-11	-49	-2	-48	49	69	-45	181
18	461	486	-25	51.5	51.61	- .11	423	447	-24	-45	-6	-106	46	116	-67	187
19	486	487	-1	51.3	51.58	- .28	424	446	-22	-2	-15	-97	15	99	-81	268
20	463	489	-26	51.6	51.55	+ .05	418	446	-28	-47	+3	-123	47	131	-69	176
21	407	490	-83	51.7	51.52	+ .18	425	445	-20	-149	+10	-88	150	175	-30	176
22	467	491	-24	51.6	51.49	+ .11	402	444	-42	-43	+6	-185	43	190	-77	172
23	527	492	+35	51.9	51.46	+ .44	400	444	-44	+63	+23	-194	67	204	-71	20
24	509	493	+16	51.8	51.43	+ .37	403	443	-40	+29	+20	-176	86	180	-78	85
25	552	495	+57	51.9	51.40	+ .50	416	442	-26	+103	+27	-114	106	155	-47	15.
26	553	496	+57	51.6	51.37	+ .23	421	442	-21	+103	+12	-92	104	139	-42	6
27	562	497	+65	51.5	51.34	+ .16	432	441	-9	+117	+9	-40	118	125	-19	4
28	555	498	+57	51.7	51.31	+ .39	440	440	0	+108	+21	0	105	105	0	12
29	577	499	+78	51.4	51.28	+ .12	433	440	-7	+140	+6	-31	140	143	-12	8
30	581	501	+90	51.5	51.25	+ .25	433	439	-6	+162	+13	-26	163	165	-19	4
31	585	502	+83	51.7	51.22	+ .48	442	438	+4	+149	+26	+18	152	153	+7	10
Feb.	471			51.6			517									
Mar.	483			51.7			449									
Apr.	521			50.7			428									

All the computations used as the basis of my research have been made in this way. About 1,500 tables like Table 2 have been constructed in preparing the results of this Bulletin. The great variety of forms in the publications of observatories, since scale divisions, British, metric, and C. G. S. units occur, renders the work tedious. An improvement would be made by publishing the coordinates (dx , dy , dz), and (σ , s , α , β) as above, since each observatory should contribute these as material available for general scientific work.

SOME REASONS FOR THE SLOW ADVANCEMENT OF THE SCIENCE OF TERRESTRIAL MAGNETISM.

This leads to a few remarks on the causes of the singularly slow advance that terrestrial magnetism has made as a science toward a satisfactory system of fundamental physical laws. For it is plain that while observations have been accumulated by the million, the primary laws of the sources of the variation of the forces are still the subject of discussion. This state of affairs may be referred to three lines of thought that have pervaded all previous analyses of magnetic observations: (1) The records have generally contented themselves with displaying the variations of the individual components taken separately. Thus the curves of Horizontal, Vertical, Total forces, Declination, and Dip occur in nearly every volume, but no attempt has been made on

a large scale to construct the corresponding vector system of impressed forces acting upon the entire earth, which will produce the same deflections in each element at each station. This has, on the other hand, been the leading idea of my computation, and out of it has emerged two definite vector systems, impressed upon the normal terrestrial field to produce the observed resultants.

(2) The prominence given to the potential, and the interpolation from station to station by the Gaussian Harmonic analysis, has probably tended to retard the elucidation of the origin of the variations of the field, because the excessive complication of the computation has really hindered the detection of the system of forces depending upon an external potential. It would seem preferable to disentangle the vector systems from each other, and from the normal field, then to study their behavior, and thus form a conception of the type of potential required. It is now seen that the interactions of the solar and the terrestrial magnetic fields well nigh overwhelm any simple potential action in the complex resultants, and thus obscure the solution of the problem.

(3) The common practice of subdividing the year by arbitrary calendar months, and taking the means for thirty-day blocks, evidently cuts to pieces any natural period which may happen to be running through the observations, but not coinciding exactly with the month divisions. This has been the natural course to pursue, however, so long as any such working period remained undetected, and hence the first logical step was to work out the periodic action within the observations, if such exists. At the outset, before any result could be found, it was necessary to employ the monthly means as representing approximately points on the normal field, and interpolating as explained. The discovery of the 26.68-day period, as the outcome of this method, enables us to construct an ephemeris dividing the total set of observations into periodic parts, and the means of these sets, instead of the thirty calendar days of the months, should be taken as the representative points of the normal field.

The repetition of the work thus implied has not been undertaken. When the laws of the secular variation of the normal field are known, a further improvement may be made in determining H., D., V., and hence a more accurate computation of the impressed vector systems. Enough has been done, however, to show that the apparently accidental variations in the daily means are really the effects of physical forces, attributed to the polar action of the sun, and not due primarily to instrumental defects. The observations are undoubtedly worthy of great confidence whenever the work has been carefully performed in the observatories.

DIAGRAMS GIVING SOME FEATURES OF THE COMPONENT MAGNETIC POLAR FIELDS.

Although it is anticipating the natural presentation of the results, yet in order to give an idea of the general conclusions reached, two

diagrams are added, which may be briefly described as follows: The earth acts like a permeable shell, one-fifth the radius in thickness, upon impressed external fields. Superposed upon the normal earth's field is a field nearly perpendicular to the plane of the ecliptic, deflected to pass the earth in the lines pertaining to such a system. If this field unites in composition with the terrestrial field, the curves of the earth's

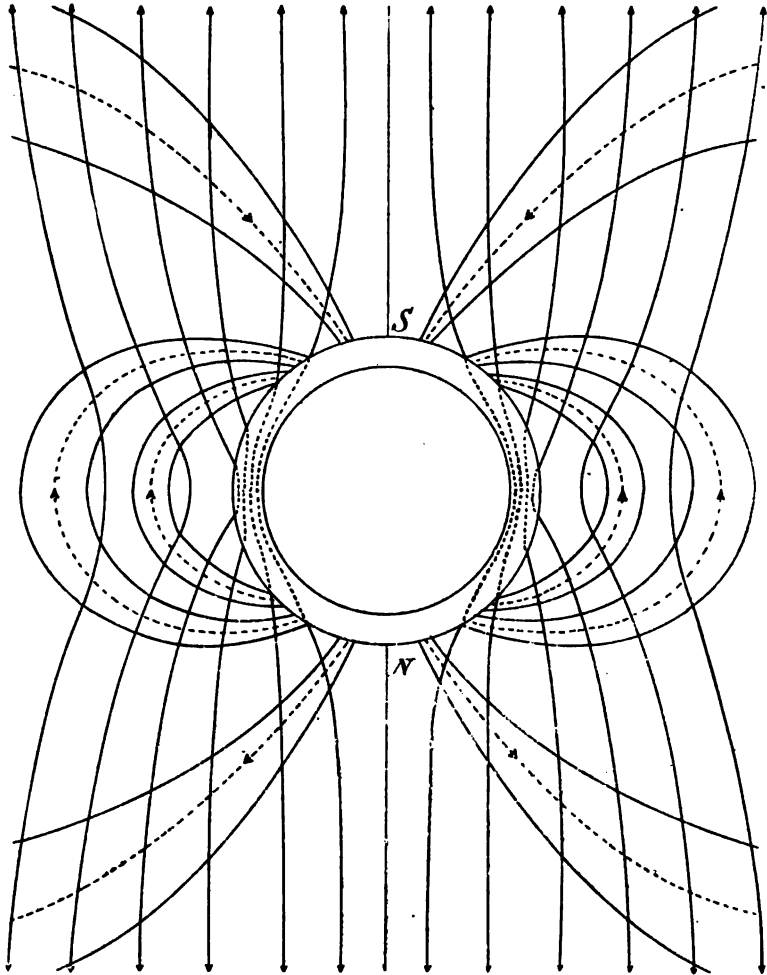


CHART 8.—Typical lines of the earth's field as deflected by the solar field.

field are expanded when it is directed from north to south, and contracted when its direction is from south to north. A variation in the strength of the external field for any cause is indicated by a change in the elements H. D. V. at the surface of the earth, and also throughout the space in its neighborhood.

The second diagram shows the resulting average variation of the

impressed field in a period of 26.68 days. It undergoes also a semi-annual periodic inversion as a whole, is subject to great perturbations, also to small abnormalities, and probably to minute wave-like variations which constitute it approximately a type of radiation. The earth's field is like a set of springs, which are deflected by the varying strength of the impressed field, itself primarily static in nature, but yet pulsating in long periods and in periods of a few seconds. The work of the transient currents of the impressed field goes one-half into magnetic energy and one-half into heat. The integral of the energy thus gained by the earth, and especially the earth's atmosphere, is apparently sufficient in quantity to modify the circulation of the currents of the air, due originally to the convection produced by solar radiation on the equatorial zone.

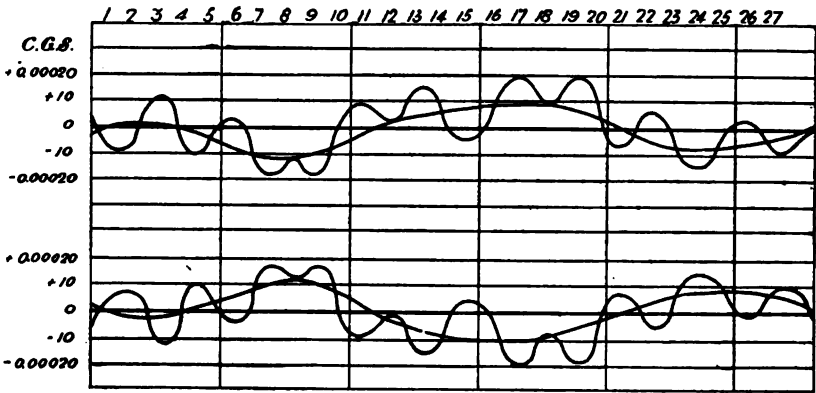


CHART 9.—Periodic variations in the strength of the solar field as observed within the earth's field. Direct and inverse types.

The axis of the earth's field is not parallel to that of the external field, but it rotates within it daily, around it annually; while also the sun rotates the external field past the earth as a whole in 26.68 days. The mechanical interaction of these systems constitutes the complexity of the problem, but it explains and renders necessary several well-known phenomena.

There is another impressed vector system, whose axis is parallel to the electro-magnetic radiation, the lines of which are distorted into a much more complicated form than those of the polar field, because the axis of the earth's magnetization, the earth having a permeable shell, is approximately at right angles to the equatorial field. This is the system observed in the diurnal variation of the needle. Thus two systems of forces are impressed from outside, one a static force, varying with the changes in its solar base; the other in intensely rapid vibration, generating a uniform field relatively to the mass of the earth or of a common magnet.

CHAPTER 2.

DETERMINATION OF THE 26.68-DAY SOLAR MAGNETIC PERIOD.

ELEMENTS OF COMPUTATION FOR 11 STATIONS, MARCH, 1887.

The form for computing σ , s , α , β for Greenwich, March, 1887, above described on page 41, is to be extended to all stations, whether the deflecting vectors are applied to the hourly or the mean daily variations of the normal terrestrial magnetic field. To show the relations simultaneously existing among these vectors at several stations of the northern hemisphere in the case of the mean variations for successive twenty-four hours, similar computations for Los Angeles, Toronto, Greenwich, Paris, Pola, Prague, Vienna, Pawlowsk, Tiflis, Zi-Ka-Wei, Batavia, are brought together for March, 1887. Those for Greenwich are transferred from the preceding Table 2. The preliminary Table 3, "Data from reports, with reduction factors to C. G. S. units," gives the name of the station, the values of H. D. V. for March, 1887, the factors needed to pass from the published data of the reports, ΔH , ΔD , ΔV (in scale divisions, parts of the horizontal force, millimeters, minutes of arc), to the corresponding equivalents in the dx, dy, dz, sixth decimal C. G. S. units, and finally the pages of the reports from which the variations of the elements are extracted.

TABLE 3.—*Data from reports with reduction factors to C. G. S. units.*

[March, 1887.]

Station.	H.	D.	V.	Reduction factors to sixth decimal dyne.	References.
Los Angeles	0.27210	-14 28.0	.....	H 1 st = 0.000030 C. G. S. D 1 st = 0.000063 C. G. S.	MSS.
Toronto .....	.....	.....	.....	H 1 st = 0.000109 C. G. S. D 1 st = 0.000046 C. G. S.	MSS.
Greenwich	0.18148	+17 51.7	0.43705	H 1 st ΔH = 0.000018 C. G. S. D 1 st = 0.000053 C. G. S. V 1 st ΔV = 0.000044 C. G. S.	II, III, VI.
Paris	0.19459	+15 58.0	0.42204	D 1 st = 0.000057 C. G. S.	B. 18.
Pola	0.21913	+10 30.4	.....	D 1 st = 0.000064 C. G. S.	10, 11.
Prague	0.19641	+10 17.1	.....	D 1 st = 0.000057 C. G. S.	IX.
Vienna	0.20583	+ 9 22.4	0.41079	H 1 st = 0.000042 C. G. S. D 1 st = 0.000077 C. G. S. V 1 st = 0.000082 C. G. S.	65, 77, 89.
Pawlowsk	0.16396	+ 0 25.6	0.46976	D 1 st = 0.000048 C. G. S.	109, 121, 133.
Tiflis	0.25701	- 1 10.8	0.37614	D 1 st = 0.000075 C. G. S.	15, 17, 19.
Zi-ka-wei	0.32970	+ 2 10.9	0.34433	D 1 st = 0.000096 C. G. S.	37.
Batavia	0.37092	- 1 50.6	0.19992	D 1 st = 0.000108 C. G. S.	104, 105, 106.

TABLE 4.—*Polar coordinates of vectors disturbing the normal magnetic field at several stations for March, 1887—Continued.*

Day of the month.	Greenwich.	Paris.	Vienna.	Pawlowsk.	Tiflis.	Zi-ka-wai.	Batavia.	Mean values for the European stations.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-ka-wai.	Batavia.	Mean geographical direction of vector.
	Vertical angle α [sign + is below horizon].								Azimuth angle β_1 [rotation from geographical north to west].											
1	+46	+54	-56	+26	+81	-85	-61	+30	309	343	130	29	61	6	57	21	66	247	58	N
2	+07	+34	-63	+48	+44	+76	-64	+26	345	233	108	9	20	7	32	40	328	180	349	N
3	-26	-19	-40	-9	+13	-88	-51	-14	333	357	43	16	16	0	18	29	7	312	356	N
4	-13	-4	-46	-4	+12	-57	-38	-6	10	6	44	18	26	7	26	44	17	15	347	N
5	+86	+37	-89	+64	+27	+30	-13	+5	69	32	45	349	8	.....	29	43	9	350	354	N
6	+32	-28	-17	+8	+24	+50	+66	+15	113	130	221	244	236	.....	215	233	221	180	220	S
7	+45	-70	-11	+50	+28	+39	+38	+38	102	185	204	261	229	.....	191	219	192	175	135	S
8	-35	-27	-19	+43	+10	-66	-10	+19	147	178	192	142	258	.....	194	208	194	189	314	S
9	-34	+25	+2	-10	-34	-26	-26	+17	146	144	203	179	204	.....	191	192	195	185	179	S
10	+10	+12	+11	+14	-68	+50	-68	+23	166	173	151	359	55	.....	181	164	206	187	96	S
11	+30	-26	-3	-28	+21	-37	-68	-20	158	180	208	258	236	202	205	229	230	172	357	S
12	+44	-19	+18	+57	-27	-58	-35	-22	151	311	190	237	191	219	198	217	194	188	348	S
13	-42	-57	-56	+8	-51	-70	-58	+20	29	229	201	321	340	106	238	304	40	253	37	NS
14	+7	-42	+10	+2	+21	-62	-62	-0	357	352	174	37	29	160	65	89	32	191	188	NS
15	-55	-32	-24	-28	-9	+13	-48	-9	146	222	198	205	54	133	21	58	29	187	247	NS
16	-18	-84	+19	-19	-5	-3	+43	-21	111	191	208	196	197	205	206	237	233	165	180	NS
17	-45	-73	+17	+34	-0	-56	+41	-13	22	237	199	356	90	162	53	91	39	191	194	NS
18	-07	-56	-1	+24	-0	+00	-28	-21	22	356	205	327	49	125	18	28	17	6	271	NS
19	-61	-18	+2	+14	-9	-58	-47	-18	3	353	286	354	0	102	1	357	15	8	340	N
20	-69	-21	-24	+2	-10	-12	-45	-24	59	185	194	11	33	255	5	334	359	354		N
21	-30	+31	-47	+23	-28	-74	+26	-10	136	148	194	215	172	160	201	219	211	4	184	S
22	-77	+49	-80	-18	-64	-31	-62	-0	155	157	190	229	170	172	103	166	174	7	236	S
23	-71	+86	-71	-44	-88	+36	-42	-9	189	152	38	235	166	268	126	240	317	19	348	S
24	-78	-10	-44	-49	-4	+46	+17	-15	179	128	53	189	181	135	166	157	180	243	191	S
25	-47	64	+67	+15	-64	-32	-46	+7	296	31	33	194	119	0	72	45	180	357	181	NS
26	-42	87	+57	+40	-73	-72	+45	+14	120	150	24	328	62	44	48	53	359	14	21	NS
27	-19	+78	+52	+43	-84	-84	+63	+14	314	336	22	97	107	12	28	75	35	178	286	NS
28	0	+72	+54	+43	-83	-67	+69	+17	245	321	30	174	136	294	38	102	91	176	221	NS
29	-12	+17	+3	+16	-76	-82	+62	-10	327	31	21	15	4	96	11	65	52	201	82	NS
30	-19	-3	-13	-26	-58	-63	49	-5	329	348	22	16	14	45	15	28	14	327	342	NS
31	+7	-3	-27	-13	-46	-48	+33	-16	345	13	28	19	.....	44	16	20	20	349	344	N

σ 61.6. s 85.7. $\cos \alpha$ 0.7188. α $44^\circ 3'$.

DISCUSSION OF THE RESULTS OF THE TABULATIONS.

An examination of the Table 4 of σ , s , α , β for eleven stations, March, 1887, two situated in North America, seven in Europe, and two in eastern Asia, thus embracing 180° or more in longitude, shows that the magnetic action is simultaneous throughout the hemisphere. This is evident from the fact that the values of σ s tend to rise and fall together, in spite of many irregularities at the individual stations, whose exact cause may be referred partly to instrumental and partly to local conditions; also the values of the azimuth angle β_1 show a series of sudden reversals, as between March 5 and 6, March 20 and 21. Against each day is placed the letter N when the values of β_1 are in the large majority of instances directed northward, S when pointing southward, and NS when partly northward and partly southward, the field being then only irregularly disturbed from its normal state. The angle $\beta_1 = \beta +$ the magnetic declination of the station, and it gives the azimuth counted from the geographical north. This systematic reversal of the direction of the impressed deflecting forces over the entire northern hemisphere, extending also to the southern hemisphere at the same time, as can be readily demonstrated, is of prime importance in the solution of

our problem. It shows that only an extraterrestrial magnetic field can be primarily concerned in these variations of the earth's field taken as a whole from day to day, for the following reasons: If the variation is due to local changes in the earth's intensity of magnetization, it would not be simultaneous over both hemispheres; if it were due to changes in the magnetization within the earth taken as a whole, the variation in the external field would be that of vectors directed along the normal lines of force; if the disturbing vectors are not along the normal lines, but athwart them, as indicated in Chart 8, and the disturbance is simultaneous over the entire globe, it can happen only by the earth as a whole being immersed in an external field of greater or less strength than that contributing to the earth's normal field. If the earth's magnetization is constant and the earth is immersed in a uniform external field, then a normal steady field will surround the earth, compounded of these two; this is the observed normal H_0, D_0, V_0 . When the external field varies, the $\Delta H, \Delta D, \Delta V$ thus arising show whence the cause of the variation resides. We do not need to laboriously compute potentials when the question is so immediately settled by the direction of the deflecting vectors, whether the disturbances of the normal field come from the outside or inside the earth.

VALUE OF THE ANGLE α FOR THE EUROPEAN FIELD.

Turning to α the altitude angle of the vector, it is seen that the irregularity in its values is very great and that this is the least useful of the elements. By comparing a large number of months, extending over several years, it is concluded that in the northern hemisphere positive values of α accompany southerly values of β ; in a word, that the deflecting forces enter the northern hemisphere from north to south; they emerge in the southern hemisphere when directed southward (Chart 8). At each station on the average, the vector enters the earth at a constant angle; the field is therefore moved as if a component, forward or back, were exerted along a definite line, the amount of the give or take registering the strength of the external field.

To determine the values of the angle α , it is seen, by comparing the mean values of the horizontal component σ and the total vector force s for the same interval of time, that they stand in a nearly constant ratio to each other, $\sigma = s \cos \alpha$; this is persistent for a given station, from year to year. Confining the mean values in the case of March, 1887, to Greenwich, Paris, Vienna, Pawlowsk, Tiflis, in order to compare stations having about the same locality and having the same relation to the external field, we find the mean value of σ for March, 1887, 61.6; the mean value of s for March, 1887, 85.7, and hence $\cos \alpha = 0.7188$; $\alpha = 44^\circ 3'$.

TABLE 5.—Angle α for European stations, by periods.

	1886.				1887.			
	σ	s	$\cos \alpha$	α	σ	s	$\cos \alpha$	α
1	99	118	0.84	33	51	75	0.70	46
2	64	77	0.85	32	68	81	0.78	39
3	99	130	0.77	39	61	94	0.65	49
4	88	124	0.71	44	62	81	0.77	40
5	91	110	0.84	33	73	91	0.82	35
6	79	111	0.73	43	64	85	0.77	40
7	67	126	0.53	58	61	86	0.71	44
8	65	104	0.63	51	73	90	0.81	36
9	73	105	0.77	40	78	106	0.74	42
10	105	123	0.87	30	76	100	0.76	41
11	88	114	0.79	38	75	94	0.80	37
12	93	109	0.87	30	63	82	0.77	39
13	76	96	0.80	37	69	99	0.70	46
14	.....	.....	.....	.....	68	85	0.81	36

Mean α , 1886; $39^{\circ} 5'$; 1887, $40^{\circ} 42'$.

If the values of σs are thus combined by the periods told off from the ephemeris soon to be constructed, 13 in 1886, and 14 in 1887, the individual values of α for each period are given in Table 5. The mean angle α for 1886 is $39^{\circ} 5'$, and for 1887, $40^{\circ} 42'$. For Europe generally it is about 40° , and this value persists for as many years as the angle has been followed in our computation.

VALUE OF THE ANGLE β_1 FOR THE EUROPEAN FIELD.

From the same tables the mean angle β_1 is about 7° west of north for Europe, as found by taking mean values of the angle. These angles, $\alpha \beta_1$, determine the mean line along which the vector impinges upon the stations of Europe. Likewise the angles $\alpha \beta_1$ have been determined for all available stations in both hemispheres. The result is that these vectors are impressed on the earth *nearly along the magnetic meridians, and as if radiating from the center of the auroral ovals*, being perpendicular to the isochasmen. (van Bemmelen, Meteorol. Zeit., Sept., 1895.); also that they touch the surface of the earth in the lines of the diagram No. 8, as if the earth were a shell of permeable magnetic material. These angles can be constructed with accuracy from the discussion of many observations. Since the vertical force is difficult to observe very accurately in regular observatory work, and the horizontal component is more steady and reliable, by the use of the mean angle α for a given station the horizontal variations can be made to check the results of the vertical-force instruments, and thus contribute substantially to their reliability.

It will be shown that an increase in the strength of the external field causes a diminution in the horizontal component and an increase in the vertical component over the entire earth and that these are equivalent to a vector pointing south and entering the earth in the northern but emerging in the southern hemisphere. This is evidently a proof positive that the earth is immersed in a variable magnetic field external to the earth and its atmosphere.

**PERIODIC REVERSAL OF THE AZIMUTHS OF THE DEFLECTING
FORCES DURING 1887.**

Having shown the method of determining the vectors of the impressed forces at several stations, attention will be directed to the behavior of the geographical azimuth angle β_1 in the year 1887 for the same eleven stations. The March values are transferred to the proper place in Table 6 for 1887. All the rows are inspected and marked N or S, as described. It is readily perceived that the year tends to be subdivided into recurring groups, consisting of about twenty-seven days, and that each 27-day group is generally composed of a short part of about eight days and a long portion of nineteen days, on the average. Thus we have:

		Days.			Days.	Total days.
Jan. 5-Jan. 13.....	9	N	Jan. 14-Jan. 30.....	17	S	26
Jan. 31-Feb. 8.....	9	N	Feb. 9-Feb. 24.....	16	S	25
Feb. 25-Mar. 5.....	9	N	Mar. 6-Mar. 24.....	19	S	28
Mar. 25-Apr. 2.....	9	N	Apr. 3-Apr. 19.....	17	S	26
Apr. 20-Apr. 28.....	9	N	Apr. 29-May 17.....	19	S	28
May 18-May 23.....	6	N	May 24-June 12.....	20	S	26
June 13-June 20.....	8	N	June 21-July 6.....	16	S	24
July 7-July 14.....	8	S	July 15-Aug. 1.....	18	N	26
Aug. 2-Aug. 10.....	9	S	Aug. 11-Aug. 28.....	18	N	27
Aug. 29-Sept. 5.....	8	S	Sept. 6-Sept. 25.....	20	N	28
Sept. 26-Oct. 3.....	8	S	Oct. 4-Oct. 23.....	20	N	28
Oct. 24-Oct. 31.....	8	S	Nov. 1-Nov. 19.....	19	N	27
Nov. 20-Nov. 28.....	8	S	Nov. 27-Dec. 15.....	19	N	27
Dec. 16-Dec. 23.....	8	S	Dec. 24-Jan. 12.....	20	N	28
Means.....	8.30			18.40		26.70

TABLE 6.

JANUARY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowak.	Tiflis.	Zi-Ka-Wai.	Batavia.	
1	327	185	204	29	42	350	351	151	332	251	349	N
2	348	226	226	161	.....	9	1	29	306	318	348	N
3	56	211	280	81	.....	351	191	167	338	328	349	N8
4	146	161	185	204	190	128	198	201	224	218	140	N
5	350	178	208	358	212	33	211	222	303	212	186	N8
6	337	350	150	41	76	15	53	32	359	344	345	N
7	356	297	99	34	21	22	27	29	7	330	352	N
8	342	0	41	39	10	32	17	357	358	343	357	N
9	341	356	61	34	10	72	18	31	1	356	351	N
10	329	349	44	21	14	34	19	27	7	359	5	N
11	335	19	58	36	20	54	40	37	13	342	341	N
12	333	358	350	32	348	355	46	14	356	352	351	N
13	329	337	45	35	23	46	29	34	11	354	343	N
14	150	166	198	208	352	98	28	351	0	355	10	N8
15	148	179	191	207	190	192	194	204	202	197	185	S
16	181	200	184	190	184	195	180	197	199	180	159	S
17	172	.....	200	222	194	241	212	170	200	176	148	S
18	173	194	212	216	212	181	229	230	209	168	241	S
19	191	204	315	237	181	193	197	204	225	193	187	S
20	165	151	322	198	165	176	212	270	212	202	185	S
21	179	118	189	181	100	154	147	213	224	169	170	S
22	261	290	1	351	.....	113	17	90	344	151	154	S
23	163	198	9	191	.....	158	108	170	170	159	168	S
24	170	158	276	265	208	248	218	192	153	88	166	S
25	159	100	27	234	174	169	163	165	225	184	167	S
26	194	69	21	193	219	204	160	208	223	127	160	S
27	179	0	322	224	4	211	171	190	211	134	164	S
28	190	70	4	287	354	276	26	156	39	91	174	N
29	171	67	10	194	18	271	75	270	245	113	164	N8
30	215	47	22	22	191	270	216	138	223	91	162	N8
31	245	353	11	352	359	285	13	270	10	89	4	N

FEBRUARY, 1887 (β_1).

1	191	309	357	207	242	226	227	222	208	327	15	S
2	274	3	34	69	.....	231	107	260	99	193	351	N8
3	196	4	353	1	.....	306	11	346	13	303	359	N
4	341	14	8	42	126	241	2	44	15	10	346	N
5	189	26	2	105	210	299	251	244	268	347	356	N
6	317	13	31	41	142	309	20	90	37	182	305	N
7	317	346	60	54	80	25	55	90	83	270	349	N
8	324	186	62	31	24	16	30	61	39	286	332	N
9	171	186	184	202	10	250	246	287	4	352	2	N8
10	12	274	191	3	28	42	14	90	337	216	342	N
11	357	184	191	36	45	60	16	8	340	346	52	N
12	158	181	211	222	208	202	218	197	195	244	142	S
13	167	208	215	209	208	238	211	229	201	195	181	S
14	152	178	210	244	211	226	231	203	207	180	205	S
15	191	211	204	198	214	209	194	218	183	177	193	S
16	212	140	204	202	89	223	203	181	198	189	201	S
17	100	166	303	183	.....	297	8	355	339	188	206	N8
18	355	193	270	352	.....	272	354	359	338	228	334	N
19	196	185	356	22	.....	160	11	310	322	1	355	N
20	227	86	199	167	179	143	160	211	202	359	126	S
21	117	198	102	177	171	136	191	176	193	133	150	S
22	137	186	97	167	163	104	191	177	205	32	200	S
23	160	175	12	196	192	211	182	217	209	354	197	S
24	176	20	16	166	215	27	179	91	154	17	186	S
25	332	17	15	67	83	26	31	33	29	20	182	N
26	56	335	16	66	282	11	33	39	48	1	162	N
27	317	152	84	113	186	21	180	300	242	2	181	N
28	5	342	24	106	66	13	37	51	22	25	199	N

TABLE 6—Continued.

MARCH, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowak.	Tiflis.	Zi-Ka-Wel.	Batavia.
1	300	343	130	29	61	6	57	21	66	247	58 N
2	345	23	108	9	20	7	32	40	338	190	249 N
3	333	357	43	16	16	0	13	29	7	312	356 N
4	10	6	44	18	26	7	26	44	17	15	247 N
5	69	32	45	349	8	.....	29	43	9	350	354 N
6	113	189	221	244	236	.....	215	233	221	180	230 S
7	102	185	204	261	229	.....	191	219	192	175	125 S
8	147	178	192	142	258	.....	194	206	194	189	314 S
9	146	144	208	179	204	.....	191	192	195	185	179 S
10	166	178	151	350	55	.....	181	164	206	187	98 S
11	158	180	208	258	226	202	205	229	220	172	357 S
12	151	311	190	237	191	219	198	217	194	188	348 S
13	29	229	201	321	340	196	238	30	40	253	37 N
14	357	352	174	37	29	160	65	89	32	191	183 N
15	146	222	198	205	54	122	21	58	29	197	247 S
16	111	191	208	196	197	206	206	237	233	165	180 S
17	22	257	199	353	90	162	53	91	89	191	194 S
18	22	366	205	327	48	125	18	28	17	6	271 N
19	3	353	296	354	0	102	1	337	15	8	340 N
20	59	186	194	11	33	255	5	334	334	359	354 N
21	186	148	194	215	172	160	201	219	211	4	184 S
22	155	157	190	229	170	172	103	166	174	7	286 S
23	189	152	38	235	166	269	126	240	317	19	348 S
24	179	129	53	180	181	185	166	157	190	248	191 S
25	296	31	33	194	119	0	72	45	190	357	181 N
26	120	160	24	328	62	44	48	53	359	14	21 N
27	314	336	22	97	107	12	28	75	35	178	286 N
28	245	321	30	174	136	294	38	102	91	176	221 N
29	327	31	21	15	4	96	11	65	52	201	32 N
30	338	348	22	16	11	45	15	28	14	327	342 N
31	345	13	28	19	.....	44	16	20	20	349	344 N

APRIL, 1887 (β_1).

1	333	347	26	18	.....	43	19	21	12	356	4 N
2	307	315	59	304	308	2	329	0	353	359	32 N
3	341	80	99	171	187	71	155	309	275	7	0 N
4	146	129	352	297	.....	89	338	332	5	1	10 N
5	166	193	211	214	.....	195	201	232	195	41	162 S
6	176	196	184	174	184	180	162	201	181	77	178 S
7	166	214	190	191	197	212	189	193	174	166	183 S
8	165	177	221	226	208	234	207	197	148	132	165 S
9	146	196	190	203	186	224	180	192	182	149	159 S
10	156	183	158	193	196	161	186	212	174	167	181 S
11	181	191	132	174	165	140	165	132	155	179	165 S
12	167	117	308	330	232	120	213	189	190	156	166 S
13	101	11	40	23	123	61	135	342	281	186	181 N
14	315	313	35	34	26	50	34	27	35	179	322 N
15	95	275	162	177	158	119	170	207	214	196	230 S
16	30	354	345	308	19	220	17	1	20	196	6 N
17	30	93	170	144	95	170	120	7	190	187	122 S
18	25	350	179	147	43	78	38	130	43	199	171 N
19	1	8	196	19	25	1	14	9	25	269	345 N
20	353	21	326	24	20	19	5	348	348	248	344 N
21	346	24	175	72	49	34	38	95	60	241	332 N
22	331	356	344	355	3	355	351	10	12	350	27 N
23	252	186	281	19	336	341	260	293	22	2	358 N
24	336	5	322	2	358	201	351	102	141	42	152 N
25	242	112	132	113	186	98	153	139	179	282	116 S
26	330	22	359	44	11	330	61	28	61	257	164 N
27	342	19	8	26	14	341	18	17	20	1	359 N
28	190	158	334	344	348	3	334	333	320	357	9 N
29	187	174	228	184	206	152	185	184	192	186	183 S
30	0	194	285	234	347	335	184	180	189	178	162 S

TABLE 6—Continued.

MAY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowsk.	Tiflis.	Zi-Ka-Wei.	Batavia.
1	248	114	232	217	228	316	223	223	318	355	116 S
2	202	200	338	44	303	222	71	133	324	260	175 N
3	153	167	294	195	203	167	162	219	308	80	190 S
4	171	144	329	216	207	241	194	198	312	311	166 S
5	148	161	318	271	204	224	207	174	123	320	215 S
6	171	183	9	241	187	226	165	10	264	190	168 S
7	140	61	323	205	202	234	191	210	236	192	247 S
8	352	61	59	340	170	194	164	78	30	188	6 N
9	326	70	38	43	176	3	93	331	4	188	396 N
10	279	57	46	25	166	41	65	46	16	1	4 N
11	324	3	66	41	100	58	82	116	26	17	358 N
12	344	347	26	19	26	31	21	24	11	369	5 N
13	90	50	33	343	357	87	10	89	74	356	178 N
14	189	146	125	65	143	86	61	57	222	367	120 NS
15	75	202	161	75	168	143	188	175	161	6	204 S
16	66	321	173	345	189	168	203	181	178	847	56 S
17	161	332	159	83	187	239	199	244	84	336	342 S
18	218	205	154	22	24	160	4	352	176	6	135 S
19	168	22	40	16	18	332	37	60	174	16	318 N
20	25	41	203	206	209	261	195	202	159	44	170 S
21	6	12	204	355	1	340	354	354	1	243	5 N
22	301	84	199	67	18	18	356	319	330	276	11 N
23	8	303	340	35	29	34	20	42	32	32	4 N
24	303	201	195	188	197	136	195	195	351	195	166 S
25	122	168	192	181	186	165	190	203	10	196	181 S
26	46	67	308	188	211	150	221	252	194	162	162 S
27	127	73	304	238	252	288	248	317	172	.....	353 NS
28	167	207	357	168	199	181	190	182	182	.....	191 S
29	171	194	322	191	100	6	112	64	179	340	329 S
30	41	300	327	305	.....	292	215	23	154	232	170 N
31	23	18	.....	308	.....	337	312	161	160	156	175 NS

JUNE, 1887 (β_1).

1	232	149	.....	344	324	299	180	290	321	176	345 N
2	5	52	.....	274	314	241	205	264	253	173	8 S
3	342	53	6	267	352	283	354	190	5	194	356 N
4	324	19	24	14	8	302	10	7	355	303	353 N
5	152	152	180	179	171	218	186	74	194	200	201 S
6	7	358	187	250	305	256	209	192	202	155	169 S
7	32	51	172	121	100	231	165	195	56	348	322 NS
8	334	206	32	18	36	316	31	47	43	83	43 N
9	832	277	338	340	334	273	28	334	16	168	14 N
10	300	96	142	101	166	259	222	134	160	198	179 S
11	296	359	168	33	24	220	112	85	95	9	33 NS
12	273	313	191	18	280	230	185	236	108	11	10 NS
13	170	198	205	203	192	195	184	35	181	232	195 S
14	63	264	188	179	194	227	195	221	208	179	175 S
15	151	43	284	197	216	257	202	224	217	196	175 S
16	155	16	3	48	199	253	167	232	240	206	209 S
17	44	32	344	336	306	285	309	326	294	93	322 N
18	349	337	23	26	23	25	21	34	337	7	18 N
19	291	331	35	51	55	108	32	25	327	350	237 N
20	43	217	234	307	17	54	311	184	35	13	174 N
21	202	262	179	217	152	86	219	147	156	0	171 S
22	191	157	209	233	212	140	226	247	194	11	171 S
23	203	156	202	286	187	152	282	239	202	356	165 S
24	161	149	190	176	155	124	353	171	168	.....	181 S
25	210	96	188	185	170	118	165	337	192	187	200 S
26	277	29	278	288	343	36	35	103	69	235	200 N
27	233	30	167	164	28	74	121	137	133	326	225 NS
28	253	4	185	302	340	71	76	232	299	354	173 N
29	347	350	81	28	19	41	39	43	19	0	190 N
30	322	11	155	33	12	43	23	358	5	357	298 N

TABLE 6—Continued.

JULY, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowak.	Tiflis.	Zi-Ka-Wel.	Batavia.
1	263	35	162	107	29	54	209	105	146	9	5 N
2	227	349	146	16	14	5	251	318	166	1	356 N
3	266	11	169	123	48	13	261	293	359	6	12 N
4	317	95	67	35	28	25	14	17	15	8	0 N
5	311	36	49	18	16	7	10	24	16	2	4 N
6	161	144	172	198	227	131	220	354	253	4	21 S
7	148	208	189	199	159	159	194	182	184	166	176 S
8	162	209	192	192	191	142	205	192	190	100	150 S
9	219	176	195	211	206	171	202	201	192	168	180 S
10	163	185	156	72	227	116	211	220	216	177	243 S
11	188	200	180	200	224	187	204	244	195	177	251 S
12	193	184	176	180	168	185	182	188	190	179	182 S
13	163	219	190	198	210	208	191	216	198	184	191 S
14	28	95	287	260	277	240	228	206	215	190	171 S
15	32	298	15	63	168	220	42	36	48	182	14 N
16	36	35	10	202	11	220	18	135	67	184	205 NS
17	7	117	248	801	228	244	270	222	262	187	196 S
18	4	20	207	294	315	297	227	348	1	189	248 N
19	90	301	228	805	42	180	57	9	322	180	203 N
20	187	284	0	344	278	311	280	220	232	179	211 N
21	13	69	196	314	210	226	221	277	186	188	161 S
22	353	42	335	1	85	17	47	6	62	204	100 N
23	46	3	16	15	18	352	-----	348	338	208	41 N
24	21	15	90	26	127	67	-----	25	58	219	110 N
25	28	20	59	23	106	39	35	356	32	221	21 N
26	326	33	36	5	78	322	8	61	58	295	343 N
27	329	350	22	30	60	350	18	16	12	348	17 N
28	355	12	336	359	70	355	14	348	328	2	2 N
29	349	1	4	10	30	303	17	18	20	347	24 N
30	351	4	345	23	43	350	29	16	31	5	19 N
31	356	10	352	21	84	331	26	3	5	349	7 N

AUGUST, 1887 (β_1).

1	179	222	11	18	8	223	21	8	9	359	352 N
2	176	212	261	218	223	191	198	187	189	155	182 S
3	171	187	144	151	194	171	182	216	202	187	174 S
4	161	167	204	186	194	176	189	225	194	172	175 S
5	176	178	158	134	117	162	131	124	172	180	182 S
6	174	106	228	226	198	179	204	209	192	188	206 S
7	167	163	217	227	171	194	207	204	202	181	185 S
8	157	201	206	227	172	189	195	200	183	172	196 S
9	19	36	257	307	244	174	220	250	278	347	325 S
10	339	47	184	345	224	142	273	258	341	174	350 NS
11	13	28	160	16	206	181	274	294	325	198	351 NS
12	349	1	191	9	328	120	312	221	344	174	359 N
13	344	354	110	35	24	77	13	13	3	6	7 N
14	344	294	172	9	9	71	359	17	2	27	245 N
15	212	339	206	220	267	197	278	279	330	4	226 NS
16	36	171	155	57	79	96	119	144	218	184	172 S
17	7	324	117	73	43	34	88	20	12	197	246 N
18	247	341	83	65	38	123	38	4	338	211	348 N
19	341	45	191	337	30	149	38	42	33	164	4 N
20	1	22	104	53	31	24	27	30	19	25	250 N
21	22	9	178	16	2	11	1	11	7	353	351 N
22	327	13	188	192	164	15	174	356	60	352	348 NS
23	330	357	179	168	79	2	15	343	5	19	13 N
24	359	13	123	17	43	7	21	43	69	9	357 N
25	321	352	42	18	32	12	15	17	17	0	3 N
26	359	11	26	1	39	11	12	12	16	360	345 N
27	8	9	13	346	12	367	354	5	24	29	337 N
28	342	166	4	288	266	333	291	321	349	5	338 N
29	189	187	16	196	208	341	224	207	197	155	191 S
30	188	182	36	199	173	256	182	184	182	164	176 S
31	223	177	16	255	57	332	186	102	176	161	176 S

TABLE 6—Continued.

SEPTEMBER, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowak.	Tiflis.	Zi-Ka-Wai.	Batavia.	
1	220	158	34	182	176	.....	176	160	184	195	186	S
2	177	169	23	189	180	.....	181	185	188	260	182	S
3	164	165	313	194	171	.....	183	196	177	343	183	S
4	198	169	9	199	162	.....	172	189	170	0	96	S
5	303	6	12	152	161	.....	169	150	166	7	11	S
6	321	343	30	76	148	.....	177	196	186	21	357	N
7	332	322	12	7	58	.....	25	17	355	317	11	N
8	349	346	10	5	.....	.....	16	27	8	178	6	N
9	2	357	21	15	.....	.....	21	27	13	207	2	N
10	351	301	30	14	.....	.....	33	52	30	179	25	N
11	75	303	299	230	.....	.....	233	357	15	190	10	N
12	6	2	256	258	.....	.....	247	330	3	148	359	N8
13	359	14	209	212	.....	.....	3	65	4	199	344	N
14	341	226	23	24	.....	.....	18	26	16	357	0	N
15	197	223	148	36	.....	.....	351	324	358	356	250	N
16	207	19	183	60	96	.....	59	97	159	225	196	S
17	324	1	10	354	111	.....	343	45	31	98	320	N
18	321	357	31	44	106	.....	292	28	13	92	359	N
19	352	11	40	24	80	.....	21	18	9	4	356	N
20	344	356	47	4	65	.....	32	17	5	10	45	N
21	325	1	41	32	.....	.....	34	43	19	166	14	N
22	344	306	164	62	.....	.....	64	45	45	98	350	N
23	74	42	363	306	.....	.....	342	294	353	6	6	N
24	30	349	211	87	.....	.....	351	226	212	357	192	N8
25	171	182	.....	270	.....	.....	299	280	309	3	5	N
26	174	189	.....	188	.....	.....	198	196	190	176	190	S
27	178	175	210	202	.....	.....	220	198	186	188	175	S
28	176	167	194	185	.....	.....	188	192	185	167	180	S
29	111	195	201	201	.....	.....	194	206	201	0	183	S
30	110	99	204	206	.....	.....	198	196	179	357	177	S

OCTOBER, 1887 (β_1).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowak.	Tiflis.	Zi-Ka-Wai.	Batavia.	
1	116	179	142	194	.....	.....	189	202	179	175	111	S
2	161	176	151	195	.....	.....	189	178	190	184	313	S
3	25	201	47	199	.....	.....	192	217	204	186	348	S
4	9	185	35	174	.....	.....	165	175	14	187	352	N8
5	327	335	34	44	.....	.....	83	38	15	218	353	N
6	285	140	56	27	.....	.....	138	35	17	273	357	N
7	346	322	23	339	.....	.....	135	11	10	186	32	N
8	11	14	79	90	.....	.....	196	5	2	273	349	N
9	342	33	50	21	225	.....	232	348	343	199	335	N
10	325	275	44	27	9	.....	44	384	5	204	351	N
11	334	329	153	327	338	.....	334	4	388	196	357	N
12	175	226	179	261	.....	.....	323	305	2	190	216	S
13	188	167	190	217	.....	.....	212	124	232	172	172	S
14	120	169	196	221	11	.....	214	202	202	182	180	S
15	286	6	172	52	22	.....	42	114	178	188	172	S
16	338	11	183	35	14	.....	57	94	69	287	20	N
17	332	329	46	31	26	.....	26	48	31	77	4	N
18	3	331	28	355	17	.....	12	33	19	330	4	N
19	340	357	66	87	21	.....	21	17	15	356	10	N
20	343	1	51	39	27	.....	21	36	23	15	15	N
21	9	349	25	25	12	.....	13	17	14	24	1	N
22	297	85	184	162	18	.....	175	21	9	215	207	N
23	174	227	247	256	326	.....	255	291	302	12	116	N
24	78	178	157	85	336	.....	116	118	120	164	168	S
25	263	49	156	82	333	.....	27	340	257	342	228	N8
26	169	146	171	165	299	.....	175	197	202	335	191	S
27	164	172	191	199	264	.....	195	206	196	171	185	S
28	146	186	261	128	232	.....	164	171	188	216	176	S
29	191	330	270	18	303	.....	337	358	301	16	112	N8
30	146	71	331	170	240	.....	186	182	206	9	177	S
31	178	246	297	167	272	.....	332	187	341	319	169	N8

TABLE 6—Continued.

NOVEMBER, 1887 (A₁).

Day.	Los Angeles.	Toronto.	Greenwich.	Paris.	Pola.	Prague.	Vienna.	Pawlowak.	Tiflis.	Zi-Ka-Wed.	Batavia.	
1	197	248	311	123	97		348	227	281	358	325	N
2	71	346	342	333			356	6	6	1	353	N
3	103	258	356	60	55		31	82	26	359	2	N
4	246	24	351	270	57		16	105	123	21	7	N
5	262	1	3	354	48		2	56	39	352	345	N
6	293	356	3	0	56		14	30	16	4	357	N
7	344	5	353	45	32		349	38	21	354	355	N
8	227	189	2	2	33		257	20	26	18	1	N
9	224	264	359	37	76			320	19	0	17	N
10	241	198	111	184	175			194	82	258	186	S
11	336	10	15	182	40		218	202	125	192	204	S
12	88	329	21	204	113		82	63	116	60	125	N
13	349	9	22	358			17	9	13	6	354	N
14	339	353	10	356			10	12	14	0	351	N
15	16	330	69	7	22		5	13	16	6	34	N
16	341	347	74	22	22		24	22	15	354	345	N
17	30	327	189	18	6		27	14	13	356	5	N
18	334	269	192	346	358		25	90	211	93	143	N
19	252	236		62	27		46	62	41	323	273	N
20	129	193		250	223		180	199	191	179	186	S
21	158	146		212	206			225	206	186	172	S
22	145	177	195	194	200		199	226	201	177	174	S
23	140	166	190	195	198		230	212	195	190	185	S
24	79	193	185	188	204		185	195	197	182	177	S
25	99	234	190	187	216		192	185	188	185	200	S
26	5	274	215	9	290		242	180	196	180	182	S
27	7	350	11	16	348		14	21	9	191	347	N
28	2	339	10	14	340		17	25	15	164	1	N
29	65	185	207	269	256		216	224	208	169	42	S
30	345	69	192	348	302		8	320	213	176	157	S

DECEMBER, 1887 (B₁).

1	62	0	287	3	167	278	358	270	0	5	49	N
2	23	345	9	8	74	286	12	90	13	359	334	N
3	354	344	18	16	66	334	25	21	1	359	13	N
4	352	352	19	16	38	336	22	30	10	367	4	N
5	344	352	20	18	58	345	33	28	15	0	3	N
6	8	98	94	108	51	346	163	302	3	357	7	N
7	19	351	200	178	176	278	194	90	0	336	284	N
8	254	335	12	25	115	302	49	39	11	9	351	N
9	351	353	354	47	74	306	21	40	12	21	8	N
10	357	357	86	20	35	348	17	40	16	2	4	N
11	353	356	48	24	27	3	26	42	11	355	344	N
12	349	353	17	11	13	1	16	30	10	0	357	N
13	20	159	340	176		128		241	265	357	354	N
14	250	325	10	12		165		41	179	135	166	N
15	309	359	18	33	358	332		36	11	359	7	N
16	189	159	123	177	183	186		188	172	120	220	S
17	126	159	198	203		203	202	219	148	190	187	S
18	185	182	356	283		5	200	50	178	167	165	S
19	121	135	205	204		232	215	214	188	93	189	S
20	176	139	80	174	200	278	242	230	186	184	185	S
21	169	177	204	218	212	251	210	203	166	186	172	S
22	188	174	196	193	194	101	195	188	170	175	179	S
23	176	336	191	212	15	262	204	176	166	181	182	S
24	274	347	350	27	12	359	21	61	329	1	150	N
25	169	306	29	20		6	26	38	314	0	355	N
26	194	116	208	201	75	174	185	256	158	132	179	S
27	111	256	205	218	5	127	206	270	150	205	241	S
28	16	206	205	286	5	116	26	130	188	25	206	N
29	345	88	214	240	18	116	24	90	209	20	265	N
30	317	140	213	197	356	118	145	1	159	303	15	S
31	322	118		152	346	69	70	73	337	29	350	N

While there is some irregularity in certain months, especially May and June, where the impressed magnetic forces always act with minimum power in the Northern Hemisphere—that is, in the summer—the periodic grouping of the N and S values of β , is a pronounced phenomenon. Furthermore, it persists certainly through the twelve years 1878–1889 with the same decisiveness as is displayed in 1887. It will be observed that the length of the groups change from N (short) S (long), to S (short) N (long) in the course of the year. This is the first symptom of the phenomenon of inversion, one whose explanation has cost much labor, as it lies at the very foundation of this complex subject. The superiority of this process in determining the magnetic periodicity over the Gaussian least-square method is obvious, because it locates definitely the date of the beginning of the period, and thus gives an epoch from which to make a long run by an ephemeris. The beginning of the period is also independent of inversion, and this is the condition in which the Gaussian method fails. It is now plain, by referring to the normal curve (chart 9), that the peculiar break at the eighth day coincides with the deepest depression in the curve, and that inversion will change the order NS to SN. A complete study of these tables, extending from 1878 to 1889, inclusive, shows that the period of 26.70 days can be usually subdivided into four portions, the divisions coming at the first, the eighth, the fifteenth, and the twenty-first days, respectively. Hence, four parallel groups of dates can be simultaneously determined. The columns NS were collected for the twelve years, 1878–1889, and the divisions between N and S marked as they occur. The apparent irregularities are merely the effects of the forces in their effort to establish the minor typical subdivisions. The common type is, however, a long central portion, with short portions, one at either end, corresponding to the depressions at the sides of the normal curve below the mean value of the vector system.

APPROXIMATE VALUES OF THE 26.68 DAY PERIOD—A TRIAL EPHEMERIS.

The approximate value of the period was computed as follows: Taking the first date of the period, as found by the process described, reduce to a June epoch by adding $26.70 \times n$ days to the given date. These June values are shown for 1878, 1886, 1887, and they indicate the accuracy with which the period tends to recur on individual dates as marked by the azimuth reversals. Counting out the number of revolutions between the epochs found for these years, with the approximate period 26.70, these separate determinations are:

June 16.5, 1878—June 4.0, 1886, 26.692 days, synodic period;

June 16.5, 1878—June 12.2, 1887, 26.683 days, synodic period;

June 4.0, 1886—June 12.2, 1887, 26.657 days, synodic period;

from which 26.68 is taken as the adopted period, with the epoch June 12.22, 1887. From this was constructed the trial ephemeris, whose

January dates for twelve years are given in Table 7. The equation of condition is formed as described in the table.

$$\Delta E + X = D - (E + n \ 26.68) \text{ residual.}$$

TABLE 7.—*Method of deducing the trial period and ephemeris.*

1878.			1886.			1887.		
Jan. 7	$7 + 26.7 \times 6 = + 160.2$	June 16.7	Jan. 19	June 1.5	Jan. 5	June 14.2		
Feb. 3	$\times 5 \quad 133.5$	16.5	Feb. 16	2.8	Jan. 31	13.5		
Mar. 1	$\times 4 \quad 106.8$	15.8	Mar. 16	4.1	Feb. 25	11.8		
Mar. 28	$\times 3 \quad 80.1$	16.1	Apr. 12	4.4	Mar. 25	13.1		
Apr. 25	$\times 2 \quad 53.4$	17.4	May 9	4.7	Apr. 20	12.4		
May 23	$\times 1 \quad 26.7$	18.7	June 5	5.0	May 18	13.7		
June 14	0	14.0	July 3	6.3	June 13	13.0		
July 12	$- 26.7 \times 1 = - 26.7$	15.3	July 27	3.6	July 7	10.3		
Aug. 13	$\times 2 \quad 53.4$	20.6	Aug. 23	3.9	Aug. 2	9.6		
Sept. 6	$\times 3 \quad 80.1$	17.9	Sept. 18	3.2	Aug. 29	9.9		
Oct. 1	$\times 4 \quad 106.8$	16.2	Oct. 15	3.5	Sept. 26	11.2		
Oct. 25	$\times 5 \quad 133.5$	13.5	Nov. 12	4.8	Oct. 24	12.5		
Nov. 23	$\times 6 \quad 160.2$	15.8	Dec. 8	4.1	Nov. 20	12.8		
Dec. 21	$\times 7 \quad 186.9$	17.1			Dec. 16	12.1		
June 16.5			June 4.0			June 12.2		

Revolutions.				Days.		Synodic period.	
1878 June 16.5 to 1886 June 4.0	109	2,909.5	26.682				
1878 June 16.5 to 1887 June 12.2	123	3,282.7	26.683				
1886 June 4.0 to 1887 June 12.2	14	373.2	26.687				
Adopted period, 26.68; epoch, 1887 June 12.22.							

EPHEMERIS.	
1878—Jan. 8.50	1884—Jan. 5.26
1879—Jan. 17.02	1885—Jan. 12.78
1880—Jan. 25.54	1886—Jan. 21.30
1881—Jan. 6.38	1887—Jan. 3.14
1882—Jan. 14.90	1888—Jan. 11.66
1883—Jan. 23.42	1889—Jan. 19.18

E = adopted epoch; ΔE its correction.
 26.68 = adopted period; x its correction.
 D = observed date derived as above.
 n = number of revolutions from epoch.

$$E + \Delta E + n (26.68 + x) = D$$
$$\Delta E + nx = D - (E + n \ 26.68)$$

Residuals.

FOUR PARALLEL SYSTEMS OF DATES; EQUATIONS OF CONDITIONS; NORMAL EQUATIONS AND SOLUTION.

In the next Table 8, under the head "Observation dates," are collected the four parallel systems of dates, all reduced to June, which were derived from the systems of NS reversals in azimuth of the angle β_1 . In each year only such individual dates were admitted to this computation as showed a clearly marked, abrupt transition. Thus in 1887 two or three dates were omitted in the summer, which changed the mean epoch from June 12.22 to June 12.87. The mean interval elapsed between the successive sets I, II, III, IV is 7.60, 9.29, 5.17 days, respectively, and those values are employed in taking out the corresponding dates from the provisional ephemeris $E + n \times 26.68$. The residuals are $D - (E + n \times 26.68)$ and are arranged in four parallel columns. The equations of condition are $\Delta E + nx = D - (E + n \ 26.68)$. Each solution I, II, III, IV is conducted separately, and the four values in the solutions for ΔE and x are given.

TABLE 8.—*Formation and solution of the equations of condition.*

Year.	Observation dates (D). [Mean for June.]				Ephemeris dates. [E + n 26.68.]				Residuals [D - (E + n 26.68)].				Revolutions.
	I.	II.	III.	IV.	I.	II.	III.	IV.	I.	II.	III.	IV.	(n)
1873	18.00	26.21	35.67	41.25	17.53	25.18	34.47	39.64	+0.42	+1.08	+1.20	+1.61	-123
1879	1.54	8.39	16.70	22.73	30.42	38.02	47.81	52.48	+1.12	+0.37	+0.61	+0.25	-110
1890	7.97	15.64	26.21	30.70	6.94	14.54	21.83	29.00	+1.03	+1.10	+2.38	+1.70	-96
1891	16.76	23.66	33.06	38.78	15.46	23.06	32.35	37.52	+1.30	+0.60	+0.71	+1.26	-83
1892	25.40	33.36	41.95	46.64	23.98	31.58	40.87	46.04	+1.42	+1.78	+1.08	+0.60	-68
1893	6.84	14.56	23.91	28.53	5.82	13.42	22.71	27.88	+1.02	+1.14	+1.20	+0.66	-55
1894	14.68	22.55	31.69	36.64	13.84	20.94	30.23	35.40	+1.34	+1.61	+1.46	+1.24	-41
1895	21.70	30.54	39.64	44.82	21.86	29.46	38.75	43.92	-0.16	+1.08	+1.19	+0.80	-27
1896	4.52	11.35	21.59	26.81	3.70	11.30	20.59	25.76	+0.82	+0.05	+1.00	+1.05	-14
1897	12.87	20.16	30.03	35.42	12.92	19.48	29.11	34.28	+0.65	+0.34	+0.92	+1.14	0
1898	20.98	29.02	36.77	41.70	19.74	27.34	36.63	41.80	+1.24	+1.68	+0.14	-0.10	+14
1899	3.00	9.99	19.34	24.86	1.58	9.18	18.47	23.64	+1.42	+0.81	+0.87	+1.22	+27
	12.85	20.45	29.74	34.91									
	7.60	9.29	5.17										

Equations of condition.				Normal equations.		Solutions.		Means.	
ΔE	$n x$	$x + \Delta E$	$I - \text{Residual.}$						
a	b	s	(n)						
1	-123	-122	-0.42 = 0	I.		I.			
1	-110	-109	-1.12 = 0			$\Delta E = +0.99948$		$\Delta E + 0.98375$	
1	-96	-95	-1.03 = 0			$x = +0.00065$		$x = -0.00072$	
1	-82	-81	-1.30 = 0						
1	-68	-67	-1.02 = 0	II.		II.			
1	-55	-54	-1.02 = 0			$\Delta E = +0.96381$			
1	-41	-40	-1.34 = 0			$x = +0.00001$			
1	-27	-26	+0.16 = 0	III.		III.			
1	-14	-13	-0.82 = 0			$\Delta E = +0.91615$			
1	0	1	-0.85 = 0			$x = -0.00109$			
1	+14	+15	-1.24 = 0	IV.		IV.			
1	+27	+28	-1.42 = 0			$\Delta E = +0.89554$		$x = -0.00246$	

Corrected period, $26.67928^d = 26^d 16^h 18^m = 9.8^s$ synodic.
 $24.86319^d = 24^d 20^h 42^m = 59.9^s$ sidereal.

Daily motion, 898.7.

Corrected epoch, June 12.22 + 0.93 + 0.57 = June 13.72, 1897.

The mean correction for the epoch June 12.22, 1887, is $+0.93375$, and the mean correction to the period 26.68 days is -0.00072 . The resulting period is—

$$26.67928^d = 26^d 16^h 18^m 9.8^s \text{ synodic.}$$

$$24.86319^d = 24^d 20^h 42^m 59.6^s \text{ sidereal.}$$

The mean daily sidereal motion is $868.7'$.

Further experience with the normal curve has induced me to change the epoch June 12.22 by $+0.93$, also $+0.57$ (arbitrary). This latter correction does two things: It throws the epoch squarely upon one of the rectangular axes of the normal curve, to be described hereafter, and it matches better with the American weather system, counting the Dakota region as one day elapsed. Being a practical adjustment of the epoch only, and not affecting the period, it has its justification in experience. My final ephemeris has the epoch June 13.72, 1887, and the period 26.67928 days. (See Bulletin No. 20.)

The periodic action of azimuth reversal within the terrestrial magnetic field is therefore the exclusive basis of the adopted period. The inference that it is the effect of the direct continuous magnetic action of the sun is so obvious as to go without saying, (1) because no other known agency is capable of producing such a persistent periodicity, and (2) because the period itself is in agreement with the known approximate period of revolution of the sun at the equator, as determined by observations on the sun spots. Thus we have, as in Table 1:

	Sidereal.
Carrington's motion at the sun's equator.....	867.0
Spoerer's motion at the sun's equator.....	881.5
Faye's motion at the sun's equator.....	863.0
Tisserand's motion at the sun's equator.....	858.0
Mean motion at the sun's equator.....	867.4

The arithmetical mean of these four results is $867.4'$, and happens to agree with my determination within $1.3'$ arc, sufficiently close to afford strong presumptive evidence that the rotation of a solar nucleus is at the basis of the two types of phenomena, one on the sun and one on the earth.

CHAPTER 3.

ANALYSIS OF THE POLAR MAGNETIC FIELD ALONG THE TERRESTRIAL MERIDIANS.

EXAMPLE OF THE COMPUTATION FOR FORT RAE.

Having shown the method of discussing the observations, and the fact that these disclose a periodicity in the variations of the actual field on the normal, as measured by the impressed vectors, we proceed to elaborate this vector system, especially in north and south lines. The average angle that the vectors make with the horizontal plane in Europe is about 40 degrees, and they act nearly along the magnetic meridians. Hence the variations of the horizontal component becomes the simplest index of the state of the impressed field at any station, and would be a complete indication of the same if the vertical angle was always constant. There is, however, much irregular disturbance in the lines of the earth's field, and it is necessary to resort to averages at each station to determine the vectors of the mean deflecting system.

It was found that the magnetic observations, complete in the three elements for a year, were available at twenty-six stations, whose names and magnetic latitude are given in Table 10, as well as the year from which the observational data was extracted. As Kingua Fjord has some gaps in the vertical force, Fort Rae is selected as the station for a specimen of the work, which is found in Table 9.

TABLE 9.—Deflecting forces separated into southward and northward groups.

Station: Fort Rae. ($4^{\circ} 43' W.$; $+62^{\circ} 39' N.$)

[β = magnetic azimuth. α = vertical angle. s = total. σ = horizontal (5th).]

	β	α	s	σ		β	α	s	σ		β	α	s	σ
1882.					1882.					1882.				
Sept. 12	186	-59	53	28	Oct. 8	20	46	70	48	Nov. 4	6	-75	D	63
13	220	58	42	24	9	39	40	33	25	5	9	-62	D	80
14	220	80	28	24	10	0	88	28	1	6	4	-62	D	68
15	222	11	29	28	11	58	0	9	9	7	292	-83	D	15
16	225	-82	65	8	12	45	3	20	20	8	13	-61	91	43
17	304	-27	4	4	13	26	30	29	25	9	225	-85	48	38
18	297	-28	2	2	14	210	-66	77	35	10	350	-42	70	52
19	204	80	20	17	15	200	14	92	90	11	292	-47	33	22
20	204	44	32	22	16	41	0	30	30	12	193	-67	D	68
21	241	78	36	10	17	332	35	32	25	13	214	-69	D	127
22	292	69	26	8	18	25	38	30	23	14	216	74	D	58
23	160	50	48	80	19	10	-39	82	24	15	317	-	81	D
24	76	-7	21	21	20	20	-40	44	34	16	14	-75	D	70
25	216	69	90	80	21	27	-62	55	27	17	148	-19	D	D
26	154	-13	36	85	22	340	-60	30	12	18	218	-46	92	72
27	257	18	9	9	23	172	-32	48	40	19	192	-7	D	D
28	180	-85	46	4	24	155	-63	50	24	20	216	71	92	80
29	202	-20	40	36	25	70	-78	45	9	21	218	44	52	38
30	129	-70	43	14	26	24	-75	105	22	22	260	26	87	78
Oct. 1	106	-44	38	26	27	55	-80	73	12	23	349	-40	72	55
2	123	85	132	11	28	330	-73	23	6	24	169	-15	53	51
3	66	-39	19	15	29	180	-83	9	1	25	129	-26	41	36
4	182	8	66	65	30	320	7	16	16	26	279	-75	46	12
5	188	-29	100	86	31	14	48	32	32	27	49	37	25	20
6	187	53	115	69	Nov. 1	3	75	26	22	28	10	72	80	25
7	20	0	30	30	2	14	54	128	75	29	30	59	65	85
					3	8	-15	54	19	30	20	20	43	41
[Group means.]					[Group means.]					[Group means.]				
S.....	191	+ 6	54	29	S.....	183	-46	55	38	S.....	204	+21	66	59
N.....	356	- 9	17	13	N.....	17	- 6	43	22	N.....	353	-23	58	43

TABLE 9.—*Deflecting forces separated into southward and northward groups—Continued.*Station: Fort Rae. ($4^{\circ} 43' W.$; $+62^{\circ} 39' N.$)[β =magnetic azimuth. α =vertical angle. s =total. σ =horizontal (5th).]

Period.	Southward.				Northward.			
	β	α	s	σ	β	α	s	σ
1882.								
Sept. 12	191	+ 6	54	29	356	-- 9	17	13
Oct. 8	183	-- 46	55	33	17	-- 6	43	22
Nov. 4	204	+ 21	66	59	353	-- 23	58	43
Dec. 1	173	-- 5	31	19	14	-- 25	63	34
Dec. 27	165	+ 23	38	21	6	-- 32	43	17
		+ 47						
1883.								
Jan. 23	202		46	20	17	+ 28	53	27
Feb. 19	191	+ 14	58	44	357	+ 23	34	25
Mar. 17	177	+ 30	45	20	3	+ 39	43	21
Apr. 13	161	-- 2	40	23	5	-- 27	38	16
May 10	196	-- 11	37	30	5	-- 15	23	17
June 5	203	+ 9	37	26	7	-- 31	29	23
July 2	208	+ 5	39	26	13	-- 21	31	19
July 29	212	+ 11	54	36	354	-- 7	31	13
Annual mean	190	+ 8	46	30	5	-- 8	39	22

The year is broken up into periods of 26.68 days, in accordance with the Ephemeris, and the σ s α β computed for each date. These are separated into two groups, the southward (heavy type) and the northward (light type), as indicated by the angles β , and the means for each group in every period are taken. These means are then collected respectively under the southward and northward headings and the means taken again. This latter set of values gives the average vector for the year at Fort Rae, as it points respectively toward the south or toward the north. In a few cases the excessive disturbances are omitted from the sums that afford the mean values in the individual periods. The chief difficulty in discussing the angle α arises from the fact that oftentimes the small or insignificant values in the variations dx , dy , dz produce very large values of α , especially if the denominator happens to be a little number. But in fact the values of α should properly be derived from only the strong values of these coordinates. These large values of α may offset many correct values, if the true angle α happens to be small, since the plus and minus signs must be observed throughout. It is concluded that the average sign of α indicates the fact of entry or emergence of the vector, while the true values of the angle can be better obtained from σ , s , as has been already done for the European stations.

In the case of Fort Rae, 1882-83, the southern vector, $\beta=190^{\circ}$, enters the earth at the angle ($\cos \alpha = \frac{3}{4}$), $\alpha=49^{\circ} 18'$, and the northward emerges, $\beta=5^{\circ}$, at the angle ($\cos \alpha = \frac{3}{5}$), $\alpha=55^{\circ} 40'$. We must conceive that the earth's magnetic field is, while under the influence of impressed impulses, compelled to adjust itself, so far as these vectors go, along a definite path, at the given station. The normal field may be subject to other vectors derived from other sources; these vectors may be of very short or very long duration, for it is evident that the normal field suffers incessant variations, which may be analyzed in the

way thus explained. Such a study ought some time to be carefully made for the several stations, and thus render very accurate the results which are derived approximately in this paper.

TABLE 10.—*Mean deflecting vectors at twenty-six stations.*

No.	Station.	Magnetic latitude.	Year.	Mean values.								Adjusted values.							
				South.				North.				South.				North.			
				β	α	s	σ	β	α	s	σ	s	σ	α	s	σ	α	s	σ
		0												0					
1	Kingua Fjord ...	77.9	1882	161	+ 5	45	27	337	— 6	27	23	45	28	54	38	23	54		
2	Fort Rae ...	76.0	1882	190	+ 8	46	30	5	— 8	39	22	53	29	55	43	24	55		
3	Point Barrow ...	73.1	1882	180	— 6	59	29	4	+ 5	55	29	60	30	58	52	24	58		
4	Cap Thorsen ...	71.1	1882	186	— 14	62	28	6	+ 8	50	23	59	30	59	52	23	59		
5	Jan Mayen ...	68.8	1882	180	+ 10	51	29	4	— 9	44	22	55	27	60	40	22	60		
6	Rosokop ...	64.4	1882	188	+ 14	43	29	18	— 6	33	10	42	23	58	33	17	58		
7	Toronto ...	62.2	1847	176	— 28	32	18	356	+ 27	25	11	34	18	56	26	13	55		
8	Sodankyla ...	61.4	1882	184	+ 5	16	15	14	— 2	14	12	31	15	54	24	11	54		
9	Washington ...	55.6	1890	179	+ 19	18	7	357	0	20	8	20	12	48	14	8	48		
10	Pawlowsk ...	55.1	1882	196	+ 10	12	10	15	— 9	10	8	18	10	47	13	8	47		
11	Greenwich ...	50.4	1887	175	— 6	13	9	359	+ 1	13	9	14	9	43	10	7	43		
12	Paro St. Maur ...	47.3	1884	177	+ 2	12	9	357	— 4	11	8	12	10	41	10	8	41		
13	Vienna ...	44.8	1882	178	+ 5	19	15	1	— 1	20	16	14	11	40	11	9	40		
14	Pola ...	41.7	1892	183	+ 14	23	16	1	— 6	17	11	16	12	38	12	9	38		
15	Los Angeles ...	40.3	1883	181	+ 10	22	12	0	— 8	23	10	17	13	37	13	10	37		
16	Tidis ...	36.1	1882	182	+ 6	15	12	13	— 7	13	11	23	19	37	17	16	37		
17	Zi-ka-wei ...	27.6	1882	187	— 4	12	32	351	+ 5	33	22	38	27	43	32	22	43		
18	Bombay ...	9.9	1883	182	+ 4	36	20	8	— 5	33	16	31	20	53	25	15	53		
19	Madras ...	3.8	1855	185	+ 2	13	11	349	— 1	12	10	19	14	36	15	11	36		
20	Singapore ...	— 6.4	1845	182	— 2	14	11	350	— 8	12	10	15	11	39	11	8	39		
21	St. Helena ...	— 11.2	1843	178	— 10	17	9	349	— 2	17	8	10	10	57	12	7	57		
22	Batavia ...	— 15.1	1890	182	+ 13	10	8	1	— 12	16	9	22	12	58	15	8	58		
23	Süd Georgien ...	— 29.8	1882	187	+ 26	52	20	8	— 17	47	15	36	19	47	31	16	47		
24	Cape Horn ...	— 33.5	1882	176	— 2	15	13	0	+ 4	13	10	25	13	44	19	10	44		
25	Cape Good Hope ...	— 33.9	1842	185	+ 16	19	11	353	— 3	10	11	20	12	43	15	9	43		
26	Hobartton ...	— 54.8	1842	176	+ 22	26	15	0	— 27	22	13	26	14	52	22	12	52		

EXTENSION OF THE COMPUTATION TO TWENTY-SIX STATIONS.

In Table 10 are collected similar "mean values" for twenty-six stations in different magnetic latitudes. The angle β shows that the vectors cling closely to the magnetic meridians; the angle α indicates that the southward vectors tend to enter and the northward to emerge in the northern hemisphere; the southward angles are more firmly developed, the vectors σ and s being almost always stronger to the south than to the north, which amounts to saying that the heavier disturbances are directed southward, and that the positive source of the external field is to the north of the plane of the ecliptic. In order to obtain the "adjusted values," the mean values of σ, s, α were plotted as ordinates along a line of abscissas extending from 0° to 180° polar distance, and an average curve drawn through them. It was not thought worth while, in the preliminary stages of the research, to attempt a more refined discussion.

DISCUSSION OF THE RESULTS.

To show the relations of these adjusted values to a mean magnetic meridian, they are distributed on Chart 10 along a circle at the angles α and lengths s , the foot of each vector standing on the station as located by its magnetic latitude. The curved bounding line shows the average

strength of the impressed vectors. The system has two maxima in each hemisphere—one over the auroral belt and the other over the trop-

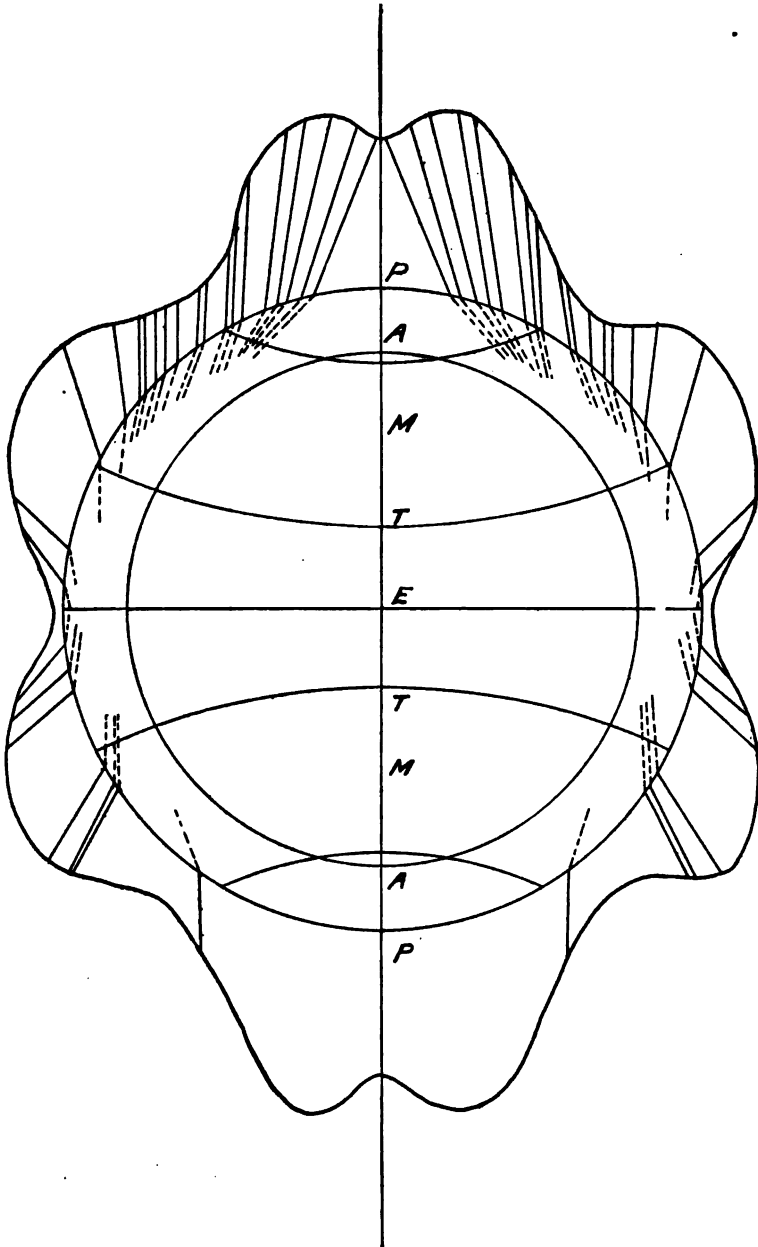


CHART 10.—Vectors of the polar magnetic field derived from observations.
 $[\mu=2.0. \quad H=0.00035.]$

ics; it has three minima—one over the poles, a deeper one over the mid-latitudes, and a third, with very small values, at the equator. The

sweep away from the poles suggests the explanation of the *aurora*, as a concentration of the impressed external magnetic force in the isochamen ovals, which also falls off in the midlatitude zones. The aspect of this vector system suggests also the theory of the entire phenomenon, namely, that the earth's shell is to some extent permeable, and is plunged in an external magnetic field whose lines of force are distorted from being parallel at a distance from the earth into the curves imposed by such a well-known magnetic system.

FORMULÆ FOR THE MAGNETIC SYSTEMS.

A set of formulæ are here collected together on Table 11 to cover the several cases arising in these problems, whose consequences can readily be followed out. Formulæ (1) for a uniformly magnetized sphere; (2) for a uniformly magnetized sphere in a uniform field, each referred to the axis x ; (3) the inflected and exflected systems arising according to the type of permeability. When the axis of the sphere is not parallel to the lines of the external field, this can be resolved parallel and perpendicular to the axis of the magnetization and be brought under these formulæ.

10305—No. 21—5

TABLE 11.

1. FORMULÆ FOR A UNIFORMLY MAGNETIZED SPHERE.

[Referred to the polar axis x .]

$$\text{Potential: } V = \frac{m}{r} - \frac{m}{r^3} = m \frac{r^1 - r^3}{r^4} = m \frac{r^1 - r^3}{r^2} = \frac{4}{3} \pi R^3 I \frac{\cos \theta}{r^3} = \frac{4}{3} \pi R^3 I \frac{x}{r^3} = \hat{\omega} \frac{\cos \theta}{r^2} = \hat{\omega} \text{ solid angle } \theta.$$

$$\text{Line of force: } N = 2\pi m (\cos \theta^1 - \cos \theta) = 2\pi \cdot \frac{4}{3} \pi R^3 I \cdot \frac{\sin^2 \theta}{r} = 2\pi \cdot \frac{4}{3} \pi R^3 I \cdot \frac{y^2}{r^3}.$$

$$\text{Asymptote: } \tan^2 \theta = 2 = \cot^2 \phi.$$

$$\text{Moment: } \hat{\omega} = 2ma = \frac{4}{3} \pi R^3 I = -R^3 F_1 = -R^3 \frac{F_0}{2} = R^3 \frac{\mu - 1}{\mu + 2} H = -\frac{F_0 R^3}{\sqrt{3} \sin^2 \phi}.$$

$$\text{Surface of cap: } 2\theta = 2\pi R^2 (1 - \cos \theta).$$

$$\text{Element zone: } dS = 2\pi R^2 \sin \theta d\theta.$$

$$\text{Flow of force: } dQ = 4\pi \cdot \frac{4}{3} \pi R^3 I \frac{\sin \theta \cos \theta d\theta}{r}.$$

$$\text{Total flow: } Q_0 = 2\pi \cdot \frac{4}{3} \pi R^3 I \cdot \frac{\sin^2 \theta}{r}.$$

$$\text{Flow through positive layer} = 4\pi M = 4\pi R^2 \cdot \pi I = -4\pi R^2 \cdot \frac{4}{3} F_1 = -3\pi R^2 F_1.$$

$$\text{Flow through great circle} = \frac{4}{3} \pi I \cdot \pi R^2 = \frac{4}{3} \pi^2 R^2 I.$$

$$\text{Mass of element zone } I dS = d. \pi R^2 I \sin^2 \theta.$$

$$\text{Mass of each layer } M = \int_0^{\frac{\pi}{2}} I dS = \pi R^2 I = \frac{4}{3} \pi \cdot \frac{R^3}{R} I = -\frac{4}{3} F_1 R^2.$$

2. UNIFORMLY MAGNETIZED SPHERE IN A UNIFORM FIELD.

[Each referred to the axis x .]

$$\text{Internal: } V_1 = \frac{4}{3} \pi I x = \frac{4}{3} \pi \frac{R^3}{r^3} I x = -F_1 x = -F_1 r \cos \theta.$$

$$-F_1 = \frac{4}{3} \pi \rho \delta = \frac{4}{3} \pi I.$$

$$\text{External: } V_e = \frac{4}{3} \pi R^3 I \frac{\cos \theta}{r^3} = \frac{4}{3} \pi R^3 I \frac{x}{r^3} = -F_1 \frac{R^3}{r^3} x = -F_1 R^3 \frac{\cos \theta}{r^3}.$$

$$F_x = X = -\frac{dV}{dx} = -\frac{4}{3} \pi R^3 I \frac{1}{r^3} \left(1 - \frac{3x^2}{r^2} \right) = -\frac{4}{3} \pi R^3 I \left(1 - \frac{3 \cos^2 \theta}{r^2} \right) = F_1 \frac{R^3}{r^3} (1 - 3 \cos^2 \theta).$$

$$F_y = Y = -\frac{dV}{dy} = +\frac{4}{3} \pi R^3 I \frac{1}{r^3} \frac{3xy}{r^2} = \frac{4}{3} \pi R^3 I \frac{3 \sin \theta \cos \theta}{r^3} = -F_1 \frac{R^3}{r^3} 3 \sin \theta \cos \theta.$$

$$F_n = X \cos \theta + Y \sin \theta = \frac{4}{3} \pi R^3 I \frac{2 \cos \theta}{r^3} = \frac{4}{3} \pi R^3 I \frac{2x}{r^4} = -2 F_1 \frac{R^3}{r^3} \cos \theta.$$

$$F_t = -X \sin \theta + Y \cos \theta = \frac{4}{3} \pi R^3 I \frac{\sin \theta}{r^3} = \frac{4}{3} \pi R^3 I \frac{y}{r^4} = -F_1 \frac{R^3}{r^3} \sin \theta.$$

$$F_\phi = X^2 + Y^2 = F_n^2 + F_t^2 = \left(\frac{4}{3} \pi \frac{R^3}{r^3} I \right)^2 (3 \cos^2 \theta + 1) = \left(\frac{4}{3} \pi \frac{R^3}{r^3} I \right)^2 (3 \sin^2 \phi + 1) = \left(\frac{4}{3} \pi \frac{R^3}{r^3} I \right)^2 \left(\frac{OQ}{OS} + 1 \right).$$

$$F_e = \frac{F_n^2}{2} = \frac{4}{3} \pi \frac{R^3}{r^3} I = \frac{4}{3} \pi I.$$

$$F_p = 2 \cdot \frac{4}{3} \pi \frac{R^3}{r^3} I = 2 F_e = \frac{2O}{r^3}.$$

TABLE 11—Continued.

3. INFLECTED AND EXFLECTED MAGNETIC SYSTEMS.

[Referred to the axis x .]

$$\text{Potential: } {}^1V_1 = \pm R^3 \frac{\mu-1}{\mu+2} H \frac{x}{r^3} - Hx. \quad V_1' = -\frac{3}{\mu+2} Hx. \quad V_1'' = -\frac{2\mu+3}{\mu+2} Hx.$$

$$\text{Force: } {}^1X_1 = \mp R^3 \frac{\mu-1}{\mu+2} H \left(1 - \frac{3x^2}{r^3}\right) + H.$$

$${}^1Y_1 = \mp R^3 \frac{\mu-1}{\mu+2} H \left(1 - \frac{3xy}{r^3}\right).$$

$${}^1Z_1 = \mp R^3 \frac{\mu-1}{\mu+2} H \left(1 - \frac{3xz}{r^3}\right).$$

$${}^1X_1' = \pm 2 R^3 \frac{\mu-1}{\mu+2} \frac{H}{r^3} + H.$$

On the axis x ($x=r$).

$$X_1' = \pm \frac{3}{\mu+2} H = H_1'; \quad X_1'' = \frac{4-\mu}{\mu+2} H = H_1'.$$

At the surface on axis x ($x=r=R$).

$${}^1X_1' = \mp R^3 \frac{\mu-1}{\mu+2} \frac{H}{r^3} + H.$$

$$\text{Magnetization: } I = \pm \frac{3}{4\pi} \frac{\mu-1}{\mu+2} R \frac{H}{r^3}.$$

$$\text{Line of force: } N = \pm \frac{\sigma p^3}{r^3} + \frac{1}{2} H p^2.$$

$$\text{Permeability: } \mu = \frac{2 \left(1 \pm \frac{8\pi}{3} \frac{I}{H} \right)}{2 \mp \frac{8\pi}{3} \frac{I}{H}}$$

Refraction: $H_1 \sin \theta_1 = H_2 \sin \theta_2$. Tangential.
 $\mu_1 H_1 \cos \theta_1 = \mu_2 H_2 \cos \theta_2$. Normal.

$$\mu_2 \tan \theta_1 = \mu_1 \tan \theta_2.$$

Sub. *e. o.* i = external, surface, internal, respectively.

Super. *i. e.* = inflected, exflected, respectively.

Upper sign = inflected.

Lower sign = exflected.

$$\text{Coordinates: } x^2 = \pm \left[\frac{2 R^3 \frac{\mu-1}{\mu+2} y^2}{\frac{2 N}{H} - y^2} \right]^{\frac{2}{3}} - y^2.$$

$$\text{Moment } M = H \frac{(\mu-1) R^3}{\mu+2}.$$

CHART OF COMBINED EXFLECTED AND INFLECTED SYSTEMS.

A rough mean integration of the length of the vectors s shows that the external uniform field averages, $H = 0.00035$ C. G. S.; trial computations bring the permeability to about 2; R can be taken as unity for a type figure; successive values may be assigned to the lines of force

$$N, \text{ from the formula } x^2 = \pm \left[\frac{0.50y^2}{y^2 - \frac{2N}{35}} \right]^{\frac{2}{3}} - y^2,$$

the coordinate values of several lines may be computed. By this process we draw chart 11, and it is only necessary to compare it with chart 8 to be assured that we have the same fundamental phenomenon.

TABLE 12.
COMPUTED ORDINATES y .

N =	Exflected.							Inflected.				
	0.0	0.5	1	2	4	6	8	10	15	20	24	27
$x = 0$	.80	.81	.82	.83	.87	.92	.95					.80
.1	.79	.80	.81	.82	.86	.92	.95					.88
.2	.77	.78	.80	.81	.85	.91	.94				.82	.95
.3	.74	.75	.77	.80	.83	.90	.93			.78	.89	1.00
.4	.68	.70	.72	.77	.81	.88	.92			.83	.94	1.05
.5	.61	.64	.67	.71	.78	.85	.90		.64	.87	.99	1.09
.6	.52	.57	.60	.65	.72	.81	.87	.50	.70	.90	1.02	1.13
.7	.38	.44	.50	.57	.68	.77	.84	.55	.75	.93	1.04	1.15
.8		.34	.41	.50	.63	.73	.82	.60	.78	.95	1.06	1.17
.9		.28	.35	.46	.60	.71	.80	.62	.81	.97	1.08	1.19
1.0		.24	.31	.42	.58	.69	.78	.64	.83	.98	1.09	1.20
1.1		.21	.30	.40	.56	.67	.77	.66	.85	.99	1.10	1.21
1.2		.20	.29	.39	.54	.64	.74	.67	.86	1.00	1.10	1.22
1.5		.19	.27	.38	.50	.61	.71	.69	.89	1.03	1.11	1.23
2.0		.18	.25	.34	.49	.60	.69	.71	.91	1.04	1.12	1.24

$$x^2 = \left[\frac{0.50 y^2}{y^2 - \frac{2N}{35}} \right]^{\frac{2}{3}} - y^2.$$

$$x^2 = \left[\frac{0.50 y^2}{\frac{2N}{35} - y^2} \right]^{\frac{2}{3}} - y^2.$$

It indicates that the nucleus of the earth is impenetrable to the lines of this magnetic field, and that hence they are exflected as by an obstacle, and pass around it; but the shell, having a thickness of about 800 miles, is slightly permeable, and collects the external lines within itself, as the easiest path for the transference of external energy. At the surface, for both branches of the system where the two media meet, the law of magnetic refraction applies.

$$\mu_2 \tan \theta_1 = \mu_1 \tan \theta_2.$$

$$H_1 \cos \theta_1 = 2 H_2 \cos \theta_2, \text{ normal component.}$$

$$H_1 \sin \theta_1 = H_2 \sin \theta_2, \text{ tangential component.}$$

The tangential components in each media are equal, while the normal change in the ratio of permeability. It is not possible to draw these vector lines perfectly, that is, to obtain the value of μ exactly, unless the internal paths of the system are known, but the approximation is so close as to give confidence in the main proposition.

Whenever the strength of the external field changes for any cause, the impressed vector at a given station varies proportionally along the

paths thus laid down; if it oscillates back and forth irregularly, it will produce such an effect as is recorded on the traces of magnetic observations; if it oscillates back and forth periodically, a wave motion is

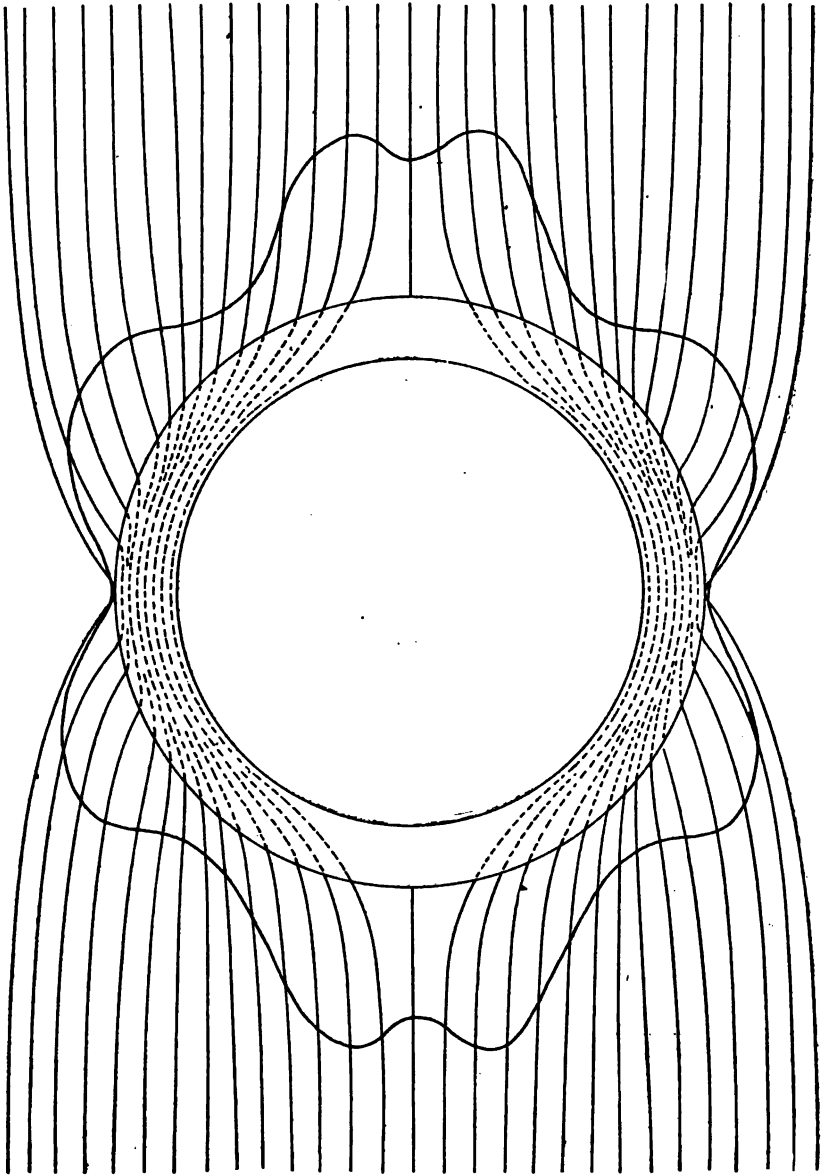


CHART 11.—Magnetic lines through a permeable shell.

set up in what would otherwise be a steady field; if the great impulses come from the north to south, then the source of energy must be to the north and the sink to the south of the ecliptic. Such oscillations,

aperiodic or periodic, are accompanied by transient induced electric currents, and the transfer of energy may be called a *radiation*; half of this energy is turned into heat and the other half into the setting up the new magnetic field by means of these transient magnetic and electric currents. Such energy may be one source of atmospheric electricity and also of the earth electric currents, especially during excessive oscillations.¹

The attendant electric phenomena in the earth's atmosphere and crust I have had little time to investigate; and indeed it is very hard to discuss them satisfactorily, because of the difficulty of securing the observations in vector form. Also concerning induced magnetic currents derived from the motions of the earth or the air currents, no special studies have been made, though the subject should be worked up if it is possible to do so definitively.

DISTURBING VECTORS DURING GREAT DISTURBANCES.

Having given examples of the vectors of the polar field taken, (1) for intervals of twenty-four hours, and (2) by the year, it is proper to also show their behavior at the same instant of time for widely separated stations. This discussion will be based upon the instantaneous impulses without the summation involved in the diurnal, the 26.68-day intervals, and the annual periods. For this purpose the three disturbances of January 4, January 28, and February 13, 1892, have been computed by the methods employed above. The directors of the observatories at San Antonio, Toronto, Washington, Greenwich, Paris, Potsdam, Vienna, Pawlowsk, Zi-ka-wei, and Melbourne had the courtesy to place at the service of the Weather Bureau the traces of their magnetic elements and the reduction constants for the required dates, and this cooperation is hereby acknowledged with thanks.

On making a comparative study of the material it was found that many differing forms of arrangement of the apparatus are employed in the observatories, so that the reduction of the data was very laborious, because of the care required in passing from station to station.

DIFFERENT SYSTEMS OF INSTRUMENTAL RECORDS.

TABLE 13.—*Arrangement of the photographic traces.*

Station.	Long.	Lat.	Trace.	Change.	Base line—Trace—Ordinates.		
					H.	D.	V.
	h	o	cm.				
San Antonio ..	6.6 W.	+29.4	37	10 a. m.	Below—down.	Above—down.	Above—down.
Toronto	5.3 W.	+43.7	44	noon.	Above—down.	Above—up.	Above—down.
Washington ..	5.1 W.	+38.9	37	noon.	Above—up.	Above—up.	Below—up.
Greenwich	0.0	+51.5	33	noon.	Above—down.	Below—down.	Above—down.
Paris	0.2 E.	+48.8	24	mid.	Below—down.	Below—down.	Below—down.
Potsdam	0.9 E.	+52.9	49	noon.	Above—up.	Above—up.	Above—up.
Vienna	1.1 E.	+48.2	37	noon.	Above—up.	Below—up.	Above—up.
Pawlowsk	2.0 E.	+59.7	36	mid.	Above—down.	Above—up.	Above—up.
Zi-ka-wei	8.1 E.	+31.2	37	6 p. m.	Below—up.	Above—up.	Below—up.
Melbourne	9.7 E.	-37.8	36	10 a. m.	Above—up.	Above—up.	Below—down.
Standard system			36	noon.	Above—up.	Above—up.	Above—up.

¹ Compare "The earth a magnetic shell." (Amer. Journ. Sci., Vol. L., August, 1895.)

Thus, in the Table 13 of the arrangement of the photographic traces, in the third space is given the length of the trace for a 24-hour run and the time of changing the sheets. When the traces are laid down so that the base line showing the time intervals increases from left to right, the trace is in some cases above and in others below the base line. The positive values of the ordinates increase sometimes up and sometimes down. They are not similarly disposed for each of the H. D. V. elements at the same station. The "Base line—Trace—Ordinates" show these differences at ten stations. It is suggested that the "standard system" indicated in the lowest line will satisfactorily take the place of the existing discordant systems, as a practical matter.

TABLE 14.
ORDINATES FOR THE DIURNAL VARIATIONS IN H. D. V.
[In millimeters.]

Hour.	San Antonio.		Toronto.		Washington.		Greenwich.		Paris.		Potsdam.		Vienna.		Pawlowak.		Melbourne.	
	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.	H.	D.	V.
Midnight.	-0.7	-0.3	+0.4	0.0	-0.7	+0.1	0.0	-0.5	0.0	+0.2	-0.3	+0.3	+1.2	-2.7	-0.4	+0.6	-1.2	0.0
1.....	-0.5	0.0	+0.3	+0.1	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
2.....	-0.2	0.0	+0.3	+0.1	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
3.....	-0.3	+0.1	-0.2	+0.2	-0.4	+0.3	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
4.....	+0.7	0.0	0.0	+0.2	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
5.....	+1.4	+0.1	+0.3	+0.3	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
6.....	+2.4	+0.1	+0.3	+0.3	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
7.....	+2.0	-1.3	+0.3	+0.3	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
8.....	+1.6	-2.1	+0.3	+0.3	-0.3	+0.2	+0.1	-0.1	+0.2	+0.3	+0.1	-0.1	+1.0	-1.2	-0.5	+0.6	-1.0	-0.1
9.....	+1.4	-1.4	+0.4	+0.2	-1.6	-0.5	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
10.....	+1.5	-2.0	+0.3	+0.2	-1.6	-0.5	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
11.....	+1.5	-2.0	+0.3	+0.2	-1.6	-0.5	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Noon.	+3.2	+0.8	-1.2	-1.1	+4.9	+0.2	-0.5	+6.2	0.0	-0.1	+1.8	-0.7	+0.2	+5.9	-0.1	+1.0	-0.3	-0.4
1.....	+0.9	+1.8	-0.9	+0.2	+5.9	-0.1	-1.3	+2.3	-0.2	+0.2	+7.7	+0.3	-0.1	+1.0	+5.5	+1.3	-0.3	-0.3
2.....	+0.8	+1.7	-0.4	+0.3	+4.5	-0.3	+0.1	+1.5	+0.2	+1.2	+3.3	+2.3	-0.1	+1.2	+2.6	+0.6	-0.3	-0.3
3.....	+1.4	+0.9	-0.1	+1.0	+3.0	-0.4	+0.7	+1.6	+0.2	+1.6	+1.4	+2.7	+0.4	+0.9	+0.9	+0.2	-0.1	+0.4
4.....	+0.8	+0.5	-0.2	+0.9	+1.6	-0.4	+0.7	+1.6	+0.2	+1.6	+1.4	+2.7	+0.4	+0.9	+0.9	+0.2	-0.1	+0.4
5.....	+0.3	+0.3	+0.2	+0.7	+0.6	-0.4	+0.7	+1.6	+0.2	+1.6	+1.4	+2.7	+0.4	+0.9	+0.9	+0.2	-0.1	+0.4
6.....	+0.7	0.0	+0.4	+0.5	+0.1	-0.3	+0.2	0.0	+0.2	+2.6	-1.0	+2.3	+0.5	-0.5	+0.8	-0.9	-0.9	+0.9
7.....	+0.3	+0.3	-0.3	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3	+2.4	-1.9	+1.9	+0.5	-0.5	+0.8	-0.9	-0.9	+0.9
8.....	+1.1	0.0	-0.4	+0.3	+0.3	-0.3	+0.3	+0.3	+0.3	+2.4	-1.9	+1.9	+0.5	-0.5	+0.8	-0.9	-0.9	+0.9
9.....	+0.2	-0.3	+0.5	+0.2	-0.3	-0.3	+0.3	+0.3	+0.3	+2.2	-2.5	+1.5	+0.3	+0.8	-0.9	+0.5	+1.0	+4.4
10.....	+0.6	-0.4	+0.5	+0.2	-0.3	-0.3	+0.3	+0.3	+0.3	+1.6	-2.8	+0.5	+0.3	+0.8	-0.9	+0.5	+1.0	+4.4
11.....	+0.3	-0.1	+0.4	+0.1	-0.8	0.0	+0.0	-0.7	+0.3	+1.5	-3.0	-0.1	+1.2	-2.7	-0.4	+0.6	-1.2	0.0
Midnight.	-0.7	-0.3	+0.4	0.0	-0.7	+0.1	0.0	-0.5	0.0	+0.2	-0.3	+0.3	+1.2	-2.7	-0.4	+0.6	-1.2	0.0

Mean ordinates from the base line to the middle line of the scale.

Equivalents of 1 millimeter in units fifth decimal, C. G. S.

Jan. 4.....	18	48	20	56	46	35	32	42	51	45	38	68	12	13	16	15	64	22	63	33	77	35	35	44	9	73	38	
Jan. 28.....	19	48	21	56	46	34	32	43	51	37	36	73	14	12	16	15	63	47	61	33	78	34	34	45	8	73	40	
Feb. 13.....	19	48	22	56	47	24	0	0	0	39	36	73	13	12	14	15	63	68	62	34	81	24	8	5	37	73	40	
Equivalents of 1 millimeter in units fifth decimal, C. G. S.																												
Jan. 4.....	4.5	9.8	10.0	10.0	4.0	16.4	4.5	6.6	8.2	2.9	2.6	2.6	7.6	8.7	9.3	5.2	6.0	1.0	4.1	6.7	6.2	6.2	5.3	4.6	5.9	10.0	7.9	7.5
Jan. 28.....	4.5	9.8	10.0	10.0	4.0	16.4	4.5	6.6	8.2	2.9	2.6	2.6	7.6	8.7	9.3	5.2	6.0	1.0	4.1	6.7	6.2	6.2	5.3	4.6	5.9	10.0	7.9	7.5
Feb. 13.....	4.5	9.8	10.0	10.0	4.0	16.4	12.0	19.2	13.3	2.9	2.6	2.6	7.6	8.7	9.3	5.2	6.0	1.0	4.1	6.7	6.2	6.2	5.3	4.6	5.9	10.0	7.9	7.5

PROCESS FOR ELIMINATING THE TRUE DISTURBANCE ORDINATES.

In order to get the pure ordinates belonging to the disturbance force proper, which is conceived to be superposed upon the mean diurnal variation at any instant of time, the following process was employed: From the records of each observatory, construct the mean diurnal trace of each element in millimeters; plot on a strip of semitransparent celluloid a scale having the length of the trace, with dots showing the mean position of H. D. V. at each hour. Such variations in millimeters are given in Table 14 for nine stations. Zi-ka-wei is omitted because its traces for February 13 were not at hand; those for January 4, January 28 were worked up with the others. These are normal variations so long as scales and sensitiveness remain unchanged. The mean ordinates from the base line to the zero line of the scale was computed, and they are given in the same table. These values enable us to place the long scale upon the disturbed trace at the mean distance for the day, and then the ordinates between the scale points and the trace itself, at the selected instant, give the values ΔH , ΔD , ΔV in millimeters, from which data the computation proceeds as before to σ , s , α , β . The distance from the base line to the zero line of the scale was determined from the position of the traces on the days just preceding and following the disturbance. The equivalents of 1 mm. in units fifth decimal C. G. S. are given at the bottom of the table. Next, certain hours and minutes were selected on the Greenwich traces for computation of the impulses, and the corresponding instants found on all the other traces, by allowing for the longitude corrections. The results σ , s , β for February 13, 1892, from 6.30 a. m. to 11.26 p. m., G. M. T., are transcribed in the accompanying Table 15.

TABLE 15.—Deflecting forces during the great disturbance February 13, 1892, at nine widely separated stations.

[Units fifth decimal.]

Hour. G.M.T.	Horizontal component ϵ .						Total deflecting force ϵ .						Azimuth angle β .						Mean									
	S. A.	T.	W.	G.	P. a.	P. e.	V.	P. e.	V.	P. a.	M.	S. A.	T.	W.	G.	P. a.	P. e.	V.		M.								
6.30	66	53	140	26	57	33	67	111	69	78	112	144	28	58	33	67	111	79	17	101	21	100	36	99	187	8	70	
7.45	27	54	39	46	86	45	64	171	62	43	157	66	50	40	55	64	172	81	180	158	98	221	280	300	355	300	254	
7.55	34	104	14	73	87	60	70	180	78	43	182	55	75	87	60	70	180	94	144	135	370	321	330	360	327	300	256	
8.07	51	23	0	70	24	47	34	144	49	63	155	53	78	32	47	35	144	62	20	154	360	209	227	230	222	327	219	
8.30	53	20	90	33	87	84	54	96	66	63	101	160	33	99	88	35	100	87	187	107	107	829	328	317	355	264	259	
8.40	29	32	82	91	13	26	38	115	53	45	88	134	91	29	28	38	117	71	201	232	360	242	307	354	278	327	265	
8.50	55	30	40	29	114	91	120	80	70	59	87	77	94	114	91	120	82	83	169	232	360	342	317	315	303	354	282	
9.25	76	163	46	17	102	26	15	127	61	27	46	48	144	103	27	127	127	127	164	154	320	313	228	327	349	289	342	282
9.50	63	111	80	81	28	55	160	124	110	80	366	56	81	111	60	162	124	141	184	157	122	244	327	360	385	334	246	
10.12	52	162	40	93	83	78	130	131	96	68	286	120	91	83	79	58	89	101	204	206	133	288	327	360	319	314	242	
10.30	54	132	163	78	96	62	95	61	124	93	394	204	87	64	100	112	91	147	205	184	144	149	90	148	325	314	267	
10.55	150	175	75	138	106	90	95	85	112	163	402	153	116	116	73	118	90	156	187	138	195	214	222	129	303	304	186	
11.05	156	234	145	112	98	90	95	98	115	161	378	212	113	109	23	121	48	203	168	184	196	196	196	193	318	302	213	
11.20	148	380	312	122	122	133	388	97	227	154	800	212	133	152	147	486	78	279	168	164	144	256	242	206	348	274	236	
1.45	214	615	280	30	58	32	388	97	199	227	680	212	133	152	147	486	78	279	168	164	144	256	242	206	348	274	236	
2.08	225	300	338	73	102	94	120	388	133	205	218	432	160	159	106	96	500	100	282	168	177	170	226	224	236	367	187	
3.00	225	300	338	73	102	94	120	388	133	205	218	432	160	159	106	96	500	100	282	168	177	170	226	224	236	367	187	
3.20	240	350	252	103	127	69	143	382	106	194	220	338	222	234	170	590	107	270	177	177	172	229	187	187	199	9	168	
3.40	240	350	252	103	127	69	143	382	106	194	220	338	222	234	170	590	107	270	177	177	172	229	187	187	199	9	168	
4.25	270	404	362	164	138	33	296	458	126	227	416	498	256	252	156	550	180	313	167	180	353	336	330	214	364	362	228	
4.35	283	374	366	146	46	180	587	374	209	220	278	458	256	252	156	550	180	313	167	180	353	336	330	214	364	362	228	
5.20	266	302	386	266	164	144	172	77	179	209	268	590	346	308	142	165	180	290	186	214	201	13	309	4	133	186	142	149
6.00	288	164	372	166	101	144	112	23	220	184	288	628	288	364	142	165	180	290	186	214	201	13	309	4	133	186	142	149
6.25	286	196	205	147	99	85	103	175	138	159	286	730	276	338	131	224	296	182	245	195	283	283	252	196	170	177	228	
6.50	302	318	234	130	29	51	103	101	174	160	802	880	268	234	131	224	296	182	245	195	283	283	252	196	170	177	228	
7.10	254	350	232	82	36	63	144	234	141	171	806	760	216	220	209	130	166	325	190	325	232	103	168	162	162	120	144	119
7.19	306	318	162	58	47	166	340	162	178	206	760	760	216	220	209	130	166	325	190	325	232	103	168	162	162	120	144	119
7.38	296	461	173	160	53	...	199	53	148	183	296	830	220	232	234	274	465	276	356	192	339	247	173	187	170	177	228	
8.30	308	570	126	127	150	210	268	455	262	295	808	840	220	232	234	274	465	276	356	192	339	247	173	187	170	177	228	
9.25	276	850	246	308	343	157	220	776	338	348	276	950	204	200	172	224	825	362	400	193	345	353	292	215	187	187	200	280
9.55	262	730	64	308	340	360	334	965	338	400	262	880	332	350	364	340	930	360	476	191	345	353	292	215	187	187	200	280
10.26	280	290	124	177	122	203	342	316	249	280	500	500	179	226	266	276	450	328	321	184	336	321	171	179	202	186	213	213
10.52	260	57	132	122	155	163	292	330	178	260	381	144	166	166	160	191	330	340	254	184	336	321	171	179	202	186	213	213
11.26	244	73	81	179	130	179	378	294	196	244	420	420	187	160	180	205	590	300	286	187	326	206	153	207	187	191	905	905

An inspection of the numbers shows the increase of the disturbance up to its maximum values of σ , s ; at the same time the large majority of the values of β are directed approximately southward, especially when the disturbance strengthens at all the stations. Toronto and Pawlowsk show unusually large values of the σ s at certain hours, and this may be due to some peculiar action of their magnets, or to excessive concentration of the external field at these localities. It is of course not my purpose to examine the records of the several stations, except as they compare with one another in a general way. The conclusion arrived at is that the disturbance impulses indicate an unusual strengthening of the impressed field; and that the great vector impulses are directed southward.

TABLE 16.
MEAN VALUES OF s , α , β .

Date.....	Jan. 4.	Jan. 29.	Feb. 13.
	°	°	°
North group.....	349 12	341 14	321 15
South group.....	187 50	171 30	195 73
Mean s	0.00053	0.00040	0.00166
Computed α	33.5°	36.6°	39.7°
Observed α	22.7°	23.5°	27.9°

The mean values of s , α , β , for the three disturbances of January 4, January 29, February 13, each taken as a whole, are collected in the Table 16, which contains the angle β in the north and south groups, the number of distinct impulses measured on the trace, the mean s , the mean computed and observed values of α . These are not the maximum but the average values of the disturbing vectors throughout the entire disturbance, the time extending to the hours of the quiet fields. The maximum values of s for February 13 is about thirty times that of the average European field and is directed southward. In almost all cases on other dates the large vectors point in the same direction. After examining all the disturbances whose records are accessible, from 1841 to 1896, inclusive, it may be laid down as a rule that the disturbances of pronounced type are always impressed upon the earth's normal field from north to south.

A complete computation of all the large and small disturbances for Washington, 1889, 1890, 1891, taking out the disturbing vectors for every half hour during the period of deflection, shows a ratio of three to one in the south quadrant over the north, east, or west quadrants. It is not easy to see how anything is lacking to verify this fact that *great disturbances are impressed southward upon the earth's field*. Also the angles α are such that lines of impressed force cut across the normal magnetic lines derived from the earth's internal magnetization, and therefore they must be propagated from outside of the earth's surface.

COMPONENTS OF THE LINES OF A SPHERICAL MAGNET IN A UNIFORM FIELD.

It is desirable to have clearly in mind what the effect is upon the lines of the normal field of a magnetized sphere immersed in a uniform field when the latter becomes stronger or weaker. Compare charts 6, 7, 8. Let AB , chart 12, be part of the normal field, however generated; let AD be lines in the impressed field, when pointing southward on the right side, and northward on the left side of the diagram, which thus

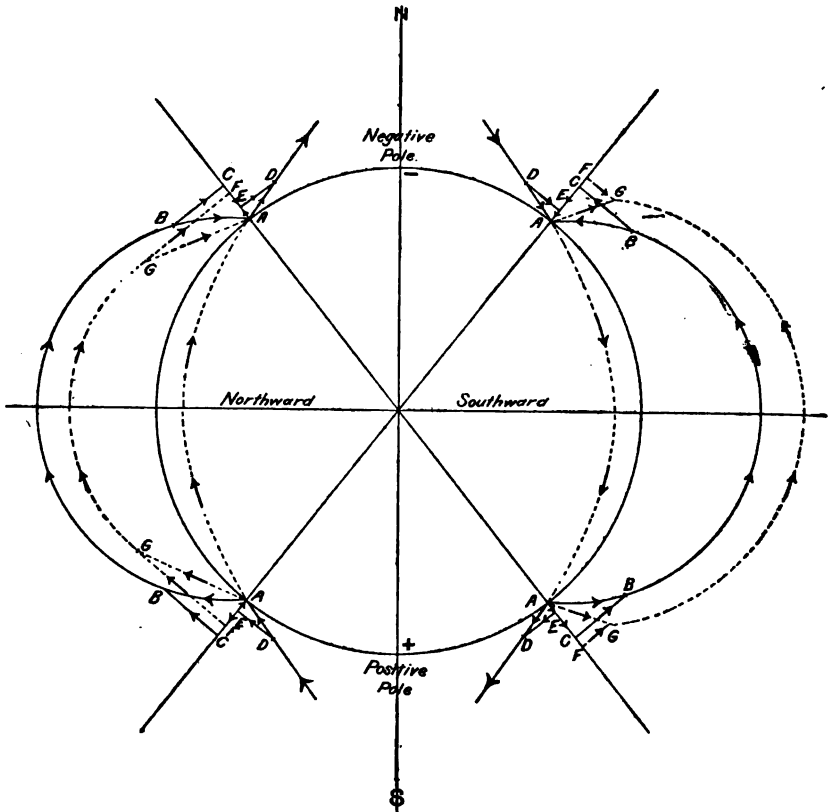


CHART 12.—Components of the impressed forces disturbing the earth's normal field in both north and south directions.

includes the case of an oscillation to each side of the mean value of the normal terrestrial and external fields. Resolve along radii of the sphere extended. The components of AB are, AC on radius, BC perpendicular to it; those of AD are AE and ED ; the vector sum of these components in each case is AG , which is a part of the resultant line of the compound field. On the right the new magnetic line is outside the original normal position, and on the left it is inside the same. An alternating impressed external field therefore expands the lines of the entire magnetic field outward or contracts them inward, thus increasing

or decreasing the stability of the sphere as a magnet. Such alternations occur irregularly in disturbances, as the traces show; they may occur periodically, with a wave-like vibration of the system. Dr. Eschenhagen's observations on the minute variations of the terrestrial field, with waves of fifteen seconds or some other short period, seem to indicate that such pulsations pertain to the earth's field as one of its permanent characteristics. Variations of the magnetic field must be accompanied by electric currents, which may profoundly affect the state of the atmospheric electric field by integration. Half of the energy of the impressed magnetic field must be expended in the system somewhere as heat, and the other half in making magnetic potential.¹

CRITICISM OF OTHER THEORIES TO ACCOUNT FOR THE VARIATIONS IN THE EARTH'S MAGNETIC FIELD.

It may be observed that if any one seeks to account for the existing magnetic field by putting the electric currents first in time as the cause of magnetic changes, then the electric system must oscillate, as the magnetic field requires. If it is attempted to account for the electric currents as convection electricity transported in the meteorological currents of atmospheric circulation, then not only must the meteorological currents oscillate back and forth, to accord with the electro-magnetic system, but they must do so simultaneously over the entire earth, because the magnetic variations are synchronous over the globe at the same instant. Since there is no evidence that this meteorological fact exists, it is inferred that the extra terrestrial seat of the magnetic field is pulsating in wave-like oscillations. Thus the magnetization of the sun may be supposed to vary its magnetization periodically or spasmodically; then these variations of energy are propagated in transient magnetic currents to the earth's field, where the pulsations are taken up and exhibited by the observed changes in H. D. V.

It may also be noted that the normal field of the earth is also a compound field. If the earth's magnetic field has a true potential, it is also plunged within an external field, assumed to be steady for the instant. What we observe as normal is the resultant of these two fields. Such an internal field would therefore have impressed upon it an external field, distributed in magnetic latitude as chart 11 indicates. Hence the Gaussian potential system may not be able by expanding terms of the harmonic orders to account entirely for the observed surface field. Indeed, it is concluded from the analysis of observations that such an external field must exist, in addition to the simple potential field, even with a heterogeneous disposition of the internal magnetization of the earth.

It may be noted that a system of vertical earth-air electric currents, such as L. A. Bauer describes (*Terrestrial Magnetism*, II, 1, p. 18), conforms to the scheme of Chart 11, if the Bauer curve is inverted, and the

¹ Compare Heaviside, *Physical Papers*, vol. 1, pp. 456, 462.

of forces displays a beautifully balanced symmetry. It is, therefore, believed that the labor of making such a model will repay each student of terrestrial magnetism. In computing the vectors of the polar field the data was obtained by taking the variations of the daily means on a slowly changing normal field derived from the means of the months—that is to say, dealing with the right-hand column of means as usually published. The vectors of the electro-magnetic field are, on the other hand, found by computing the variations of the hourly means for each month relatively to the mean of the month—that is, by simply subtracting the monthly mean along the lowest row of the page as commonly printed. There is obviously no need to make any secular changes in these quantities, because the 24-hourly means are in every case simultaneously synchronous throughout the day. The diurnal variations of the needle at any station are caused by the earth in its rotation transporting this station to the successive 24 points in the impressed field where the observations are made. Since the aspect of the sunlight field is similar once in twenty-four hours for every station on the earth, the record of stations widely separated in longitude may be made to begin on one meridian by ignoring the variations in local time, though, of course, in fact, each station is at the same moment experiencing the deflection due to that part of the field in which it then happens to be placed. The earth may thus be studied as a nonrotating body relatively to the external field by simply orienting the vectors of each station from that meridian whose plane when extended will pass through the center of the sun. By computing the vectors for each month and the mean of these for the twelve months, a mean vector system will be found with the sun in the equatorial plane. The intersection of the central meridian and the equatorial planes locates the direction of the axis of the external field before any distortion caused by the immersed earth takes place in it. The solar field has an outward diminution in induction, and hence a force directed from the sun into space. Such a magnet as the earth placed in an external field should experience deflections after the nature of couples, directed toward the sun in the northern hemisphere and from the sun in the southern hemisphere, with very well defined distribution of the forces in sheets, determined by the aspect of the curvature of the shell in the several latitudes relatively to the direction of the field. It has not yet been practicable for me to give the work necessary to elaborate analytically the magnetic fields produced under these conditions, because of the difficulties arising from the peculiar asymmetric distortion due to the lag of rotation and the temperature distribution in latitude and longitude as the result of solar radiation upon the tropics. The following scheme (chart 13), however, gives some idea of the relations that appear to exist:

CHART 13.—Schematic distribution of the disturbing vectors of a magnetized sphere, covered by a permeable shell, immersed in an external magnetic field and at right angles to it.

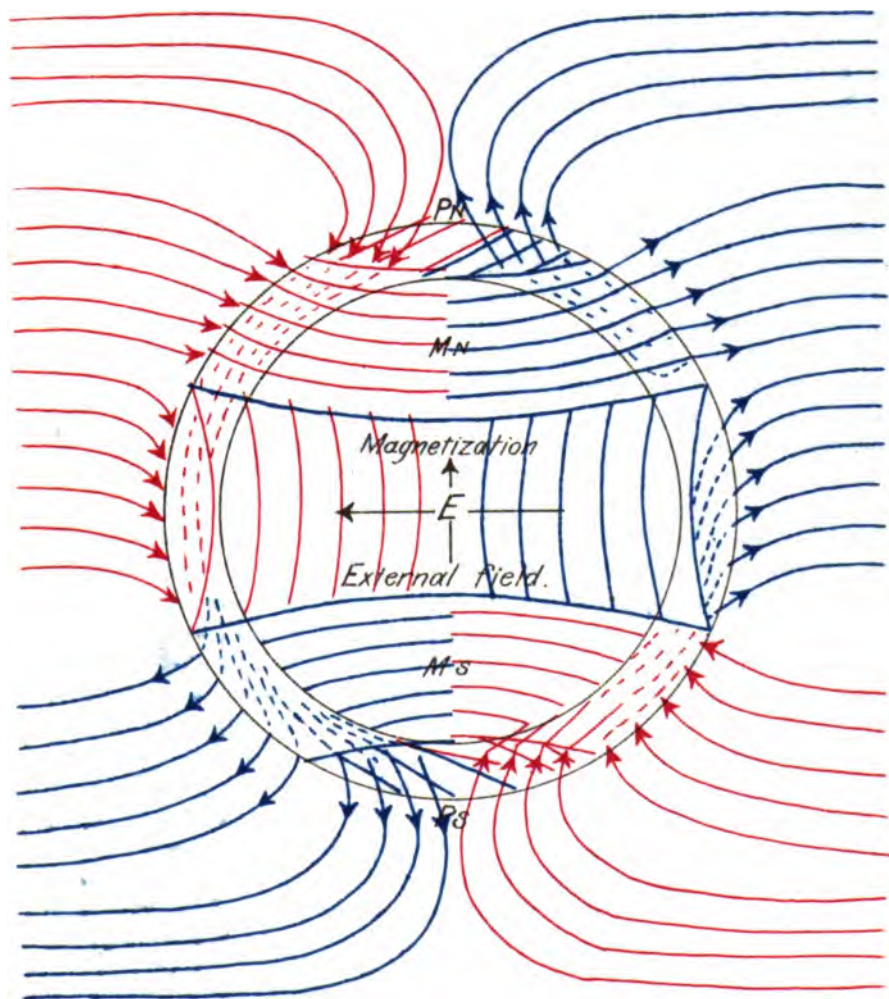


Chart 13.



A PERMEABLE SHELL INCLOSING A SPHERE MAGNETIZED AT RIGHT ANGLES TO AN EXTERNAL FIELD.

The shell may be divided into two polar caps, P_n and P_s , cut off by planes perpendicular to the axis of magnetization and nearly touching the impermeable nucleus; into two midlatitude zones M_n and M_s , having sphero-conical surfaces; and into one equatorial sphero-rectangular zone E , parallel to the axis of magnetization. If the sun lies in the plane of the diagram central to the right, its field is directed from right to left. The earth is a magnet, with its external field directed in wide curves upward. Every unit volume of the new compound magnetic field is the resultant of these two fields, now excluding the coronal field. The observations are made at the surface of the earth for the deflections, and the field can not be explored outwards, except analytically, or by model-magnets. The deflecting forces are arranged along lines which seek the path of least magnetic resistance, and that is through the shell. Each polar cap has a twisting couple, the components acting against one another in the opposite hemispheres and penetrating the shell. The midlatitude zones constitute also a couple, acting to the right in the northern zone and to the left in the southern, penetrating the shell about parallel to the ecliptic. The equatorial zone contains a couple, on the right side upward and on the left side downward, penetrating the shell merely at right angles to the plane of the orbit. These may merge into discontinuous sheets to form one system. The effective magnetic forces are the physical resultants of an extremely rapid alternating field acting upon the earth's magnetic field. Induction is probably important, as shown by the greatly increasing strength of the deflecting field in the polar caps. The temperature is also an efficient term, because magnetic effects increase with decrease of the temperature of the medium. The rotating of the earth is a term of some importance and may partly account for the lag, though this view is contradicted by the peculiar twist in the polar caps, where the axis of the couple is nearly at right angles to that of the couples in the middle zones. Convection currents of the atmospheric circulation, static atmospheric electricity, the disintegration of the radiant waves into heat, are also elements to be considered in the solution of this complex problem.

COMPUTATION OF THE VECTOR SYSTEM FOR JAN MAYEN.

The preceding remarks are based upon the results of the following computation: There are 30 stations available for the discussion of observations in H. D. V. during a year, from which the simultaneous variations ΔH , ΔD , ΔV , can be obtained. Table 17 gives the stations, their geographical position, the year of the record, and the magnetic elements in the two systems, F. D. I. and H. D. V.

TABLE 17.—Coordinates of the magnetic elements at thirty stations.

Stations.	Longitude.	Latitude.	Year.	Declina- tion.	Incli- nation.	Mag. Lat.	Horiz- ontal force.	Vertical force.	Total force.
Kingua Fjord	4 29 21 W	+66 35 40	1882-1883	72 12 W	83 52	77 52	0.06379	0.59321	0.59662
Fort Rae	7 42 55 W	+62 38 52	1882-1883	40 20 E	82 55	76 2	0.07669	0.61780	0.62234
Ugliaamie	10 26 30 W	+71 17 42	1882-1883	35 37 E	81 23	73 8	0.08940	0.58980	0.59652
Cap Thordsen	1 2 49 E	+78 28 27	1882-1883	12 49 W	80 27	71 4	0.08921	0.53006	0.53751
Jan Mayen	0 33 53 W	+70 59 48	1882-1883	29 53 W	79 2	68 49	0.09745	0.50294	0.51229
Bossekop	1 35 50 E	+69 57 29	1882-1883	4 3 W	76 32	64 25	0.12087	0.50456	0.51885
Toronto	5 17 33 W	+43 39 24	1843-1848	1 29 W	75 15	62 14	0.16325	0.62000	0.64121
Sodankyla	1 46 25 E	+67 24 30	1882-1883	1 20 W	74 45	61 24	0.13352	0.49095	0.50781
Makertown	0 10 4 W	+55 34 45	1845	25 11 W	71 15	55 50	0.15603	0.45963	0.48540
Washington	5 8 12 W	+38 53 39	1890	4 6 W	71 5	55 34	0.19860	0.57928	0.61238
Pawlovsk	-2 1 56 E	+59 41 00	1883	0 42 W	70 44	55 3	0.16380	0.48858	0.49638
Dublin	0 25 4 W	+53 21 00	1842-1843	27 17 W	70 41	54 58	0.16182	0.46166	0.48919
Wilhelmshaven	-0 32 35 E	+53 31 52	1882-1883	13 54 W	68 1	51 5	0.17773	0.44030	0.47483
Greenwich	0 0 0	+51 28 38	1883	18 15 W	67 32	50 24	0.18100	0.43762	0.47359
Parc Ste. Maur.	-0 9 23 E	+48 48 34	1889	15 45 W	65 13	47 17	0.19522	0.42369	0.46559
Vienna	-1 5 28 E	+48 14 00	1884	9 35 W	63 24	44 47	0.20554	0.41031	0.45883
Pola	-0 55 24 E	+44 52 00	1890	10 14 W	60 43	41 43	0.21948	0.39127	0.44863
Los Angeles	+7 53 2 W	+34 2 58	1882-1889	14 28 E	59 30	40 20	0.27273	0.46300	0.53730
Tiflis	-2 59 10 E	+41 43 8	1883	0 59 E	55 35	36 7	0.25742	0.37566	0.45560
Zi-Ka-Wei	-8 5 45 E	+31 12 30	1885	2 9 W	46 18	27 37	0.32911	0.34435	0.47633
Bombay	-4 51 16 E	+18 53 30	1863	0 84 E	19 18	9 53	0.37187	0.12967	0.38969
Madras	-5 20 59 E	+13 4 8	1851-1855	1 0 E	7 37	3 50	0.37383	0.05015	0.37718
Singapore	-6 55 23 E	+1 17 0	1843-1845	1 35 E	-12 41	-6 25	0.37250	-0.08393	0.38182
St. Helena	0 22 42 W	-15 56 41	1841-1845	22 46 W	-21 37	-11 12	0.25710	-0.10188	0.27655
Batavia	-7 7 14 E	-6 11 0	1888	1 47 E	-28 25	-15 8	0.37094	-0.20070	0.42175
Süd Georgien	2 24 0 W	-54 51 0	1882-1883	0 15 W	-48 53	-29 48	0.25668	-0.29405	0.38033
Cape Horn	4 41 41 W	-55 31 24	1882-1883	20 11 E	-52 55	-33 29	0.28536	-0.37760	0.47329
Cape Good Hope	-1 15 55 E	-33 56 0	1841-1846	29 7 W	-53 21	-33 54	0.20740	-0.27876	0.34745
Melbourne	-9 39 53 E	-37 48 35	1858-1863	8 28 E	-67 20	-50 8	0.23567	-0.56409	0.61134
Hobartson	-9 49 50 E	-42 52 30	1841-1848	9 47 E	-70 36	-54 50	0.20700	-0.58790	0.62319

The station Jan Mayen, 1882, 1883, is transcribed in detail for every month except August, when there were no observations. The monthly mean is subtracted from the successive hourly means for ΔH , ΔD , ΔV , and these are transformed into σ , s , α , β . The annual means are taken and placed in the last column of Table 18.

TABLE 18.—Diurnal deflecting forces at Jan Mayen, 1882-1883.

Hour.	January.				February.				March.				April.			
	σ	s	α	β	σ	s	α	β	σ	s	α	β	σ	s	α	β
Mid.	45	53	+38	172	54	80	+48	195	27	71	+68	195	44	76	+55	195
1	58	70	+37	188	49	83	+55	202	30	73	+65	222	35	65	+57	315
2	58	60	+50	206	70	103	+48	132	76	102	+41	208	53	54	+44	230
3	30	40	+42	225	60	68	+40	227	100	125	+37	213	62	68	+87	223
4	35	53	+40	222	60	72	+34	232	100	118	+32	217	72	77	+22	234
5	45	46	+10	208	60	63	+18	238	90	95	+18	214	78	78	+5	236
6	22	22	-8	234	30	30	-2	272	65	65	+5	205	82	85	-13	230
7	16	20	-33	320	25	27	-18	280	50	57	-30	214	46	53	-30	223
8	20	22	-23	358	27	32	-33	330	13	57	-28	228	23	30	-40	236
9	22	22	-6	2	28	30	-17	345	13	20	-48	235	20	22	-18	259
10	25	26	+15	2	25	25	-4	347	61	63	-13	2	9	11	-40	75
11	32	33	+17	5	40	40	-4	358	42	46	-21	2	16	16	-10	20
Noon.	45	46	+13	9	55	57	-18	3	60	67	-25	12	41	41	-14	8
1	46	46	+6	9	73	74	-8	10	70	78	-26	20	73	74	-8	9
2	48	48	-1	12	80	84	-18	9	102	108	-22	15	83	84	-8	12
3	62	63	-12	2	52	58	-22	15	92	102	-25	16	87	91	-18	16
4	51	55	-20	10	32	53	-53	35	105	120	-28	14	92	100	-25	20
5	45	52	-39	10	22	58	-67	45	81	99	-34	25	87	97	-36	20
6	11	40	-74	16	54	80	-48	66	40	66	-51	60	70	84	-34	54
7	40	65	-54	144	37	56	-49	100	38	64	-54	88	54	74	-44	71
8	33	50	-50	143	33	41	-50	88	51	53	-15	112	57	66	-30	89
9	46	50	-22	158	80	80	-2	140	46	46	0	148	35	36	+17	110
10	30	31	+16	144	53	57	+20	142	40	50	+36	143	62	70	+37	178
11	40	45	+30	170	13	32	+64	200	46	75	+52	183	78	100	+38	174
Mid.	45	53	+33	172	54	80	+48	196	27	71	+68	195	44	76	+55	195

TABLE 18.—*Diurnal deflecting forces at Jan Mayen, 1882-1883—Continued.*

Hour.	May.				June.				July.				September.			
	σ	s	a	β	σ	s	a	β	σ	s	a	β	σ	s	a	β
Mid.	84	98	+30	193	63	64	+12	175	46	78	+53	185	28	40	+44	187
1	77	97	+38	189	61	67	+26	200	97	130	+42	200	44	60	+42	206
2	75	100	+41	209	105	112	+32	195	100	145	+46	204	58	65	+28	214
3	93	105	+28	213	125	127	+11	207	140	171	+35	198	100	110	+24	200
4	100	104	+15	216	127	130	-11	210	104	127	+34	210	61	61	+5	211
5	92	92	-2	214	128	140	-22	212	100	109	+23	215	56	57	-13	214
6	72	75	-16	215	94	116	-37	220	76	76	+1	222	48	56	-29	200
7	41	45	-24	222	46	90	-59	227	70	70	0	228	15	30	-61	182
8	20	33	-28	230	34	68	-70	233	60	61	-7	218	15	25	-54	238
9	12	17	-46	230	16	70	-74	235	33	35	-19	210	9	13	-46	352
10	8	15	-56	125	16	55	-71	270	9	11	-43	270	6	7	-30	0
11	18	18	+89	8	29	70	-65	347	25	25	-10	348	30	30	-1	22
Noon.	44	45	+14	17	46	80	-54	3	29	32	-26	8	60	61	+8	12
1	77	77	0	10	62	73	-58	358	86	90	-15	4	42	43	+12	30
2	94	94	-3	8	97	130	-41	13	88	98	-25	15	83	83	+3	16
3	125	125	-3	12	104	135	-41	13	133	146	-24	15	90	90	-5	13
4	110	112	-12	10	140	173	-36	16	148	163	-25	12	90	90	-7	10
5	117	125	-19	13	104	164	-51	24	100	120	-13	10	82	86	-17	20
6	95	112	-31	25	97	162	-53	25	120	140	-71	28	70	80	-28	38
7	58	70	-32	65	80	150	-58	40	82	100	-35	51	55	64	-31	72
8	44	65	-48	93	64	128	-60	92	45	60	-40	45	43	50	-33	86
9	50	52	-18	117	66	107	-51	106	54	57	-22	100	62	62	+6	136
10	40	42	+18	128	45	67	-48	134	21	22	-14	104	79	86	+24	156
11	63	77	+35	169	32	39	-32	145	49	65	+41	165	28	40	+45	170
Mid.	84	98	+30	193	63	64	+12	175	46	78	+53	185	28	40	+44	187

Hour.	October.				November.				December.				Annual means.			
	σ	s	a	β	σ	s	a	β	σ	s	a	β	σ	s	a	β
Mid.	33	60	+57	210	73	95	+41	197	65	83	+38	200	51	72	+43	191
1	68	92	+47	204	78	116	+48	186	39	65	+54	190	58	84	+46	200
2	60	77	+38	210	86	102	+33	212	30	60	+58	200	68	89	+41	201
3	63	75	+32	209	66	90	+43	219	58	70	+33	119	81	95	+33	205
4	106	110	+14	207	22	76	+16	190	84	86	+15	205	79	92	+20	213
5	72	74	+12	215	57	78	+48	240	32	34	+20	210	74	79	+11	219
6	51	53	-14	214	40	44	+24	282	20	20	+12	247	55	58	-7	231
7	16	29	-58	272	00	91	-10	308	14	20	-44	240	36	40	-33	247
8	20	28	-45	316	00	60	-1	320	17	18	-21	240	29	40	-32	268
9	32	35	-28	328	50	50	-8	333	20	29	-10	352	24	31	-29	295
10	40	43	-23	342	65	65	-4	333	36	36	-4	350	27	32	-25	291
11	55	55	-12	4	47	52	-25	325	51	51	+2	5	35	40	-4	0
Noon.	106	110	-13	5	42	52	-38	359	55	55	-3	8	53	59	-14	8
1	45	50	-28	16	70	80	-29	4	61	61	-1	8	64	68	-14	11
2	73	78	-20	14	67	96	-46	20	63	65	-14	7	80	88	-18	13
3	82	85	-15	20	68	112	-40	32	68	71	-19	6	88	98	-20	15
4	66	88	-34	20	49	80	-52	88	55	60	-25	10	85	99	-29	22
5	52	70	-40	83	64	80	-50	77	25	40	-50	20	71	90	-36	28
6	35	52	-48	76	116	124	-30	42	27	40	-44	135	67	89	-47	51
7	70	71	-10	133	44	63	-46	74	13	40	-73	100	52	74	-44	85
8	45	45	+3	124	72	78	+26	132	58	64	-25	155	49	64	-29	105
9	40	45	+30	130	57	57	+3	146	55	61	-25	147	54	59	-8	131
10	52	70	+45	159	42	56	+41	170	32	34	-20	142	45	53	+13	145
11	31	38	+56	195	46	77	+58	180	34	46	+48	145	42	58	+38	172
Mid.	33	60	+57	210	73	95	+41	197	65	83	+38	200	51	72	+43	191

THE GLOBE MODEL CONSTRUCTED FROM THE VECTORS AT THIRTY STATIONS.

A table of the annual means derived in the same way for thirty stations was constructed, and should properly be given here, but is omitted because it differs merely by minor variations from the adjusted values used in making the 30-inch globe model, which was built up from this original data. There is some looseness in the harmony of the observations among the stations of each group, as may be expected from the many causes operating to produce local variations, and from the fact that the computations covered only one year at each station, while the

observations themselves are spread through forty years, 1841 to 1883. The fact of real agreement, however, indicates that the fundamental system is persistent, instantaneous in its development, and has no secular variation. On the large globe the wires which represent the computed vectors were inserted, twenty-four on a given parallel of magnetic latitude corresponding to a station, one for each hour. Each wire by its length and position shows the relative strength and direction of that impressed force which will change the normal terrestrial magnetic field into the one actually observed at the station at the given hour. The discussion of the observations of terrestrial magnetism has hitherto usually confined itself to the diurnal variation of each component, horizontal force, declination, and vertical force, taken separately. It is obvious that our process merely combines these variations into one resultant vector acting in space, and is not only as legitimate as the prevailing method, but very much more instructive. A detailed description of the vectors of the following system would therefore merely reproduce the facts stated at length in the several reports, of which it is an approximate combination and summary.

Since each vector wire represents the mean value of the impressed force acting on the average for a year, the system of vectors exhibits the distribution of the external field of force as deflected by the material of the earth acting as a magnet. When the individual vector wires were inserted on the globe in latitude and longitude for all the spaces available, it was easy to see in any locality the average trend of the vectors. The wires were therefore bent or adjusted a little to give a gradually varying vector system, these changes being the smoothing out of the irregularities to a legitimate extent; from the system thus constructed the vectors of the following Table 19 were measured. They form an approximate representation of the mean magnetic vector system, and this should be discussed on its merits, whatever conclusion it may lead us to adopt. The importance of the result is such as to warrant a complete computation of all available observations, in order to elucidate some minor points that still remain inadequately determined. The model represents a mean annual system of deflecting forces impressed upon the magnetic meridians of the earth, the sun being at the intersection of the equator and central noon meridian; the poles of the model are intended to represent the magnetic poles of the earth. Of course the magnetic meridians are modified into great circles on the globe.

TABLE 19.—Deflecting vectors of the equatorial electro-magnetic field.

[Measured on the globe model.]

[α : units fifth decimal C. G. S.; α =positive below horizon; β =in azimuth N. W. S. E.]

Station.	Mag. lat.	Midnight.			1 a. m.			2 a. m.			3 a. m.			4 a. m.			5 a. m.		
		<i>s</i>	<i>a</i>	<i>β</i>	<i>s</i>	<i>a</i>	<i>β</i>	<i>s</i>	<i>a</i>	<i>β</i>	<i>s</i>	<i>a</i>	<i>β</i>	<i>s</i>	<i>a</i>	<i>β</i>	<i>s</i>	<i>a</i>	<i>β</i>
Kingua Fjord	+78	60	40	140	60	45	145	65	50	155	73	53	170	82	55	180	92	52	185
Fort Rae	76	60	39	150	62	46	155	70	52	165	76	50	180	82	50	190	88	50	195
Point Barrow	73	58	38	155	61	48	165	72	50	175	80	46	185	85	44	195	92	45	205
Cap Thorsden	71	56	37	160	68	48	175	76	45	185	82	43	195	87	42	205	91	40	210
Jan Mayen	69	58	35	170	66	45	185	74	38	195	85	40	205	89	40	210	89	40	215
Bossekop	65	60	32	185	64	40	195	70	34	205	75	46	215	80	35	220	80	35	225
Sodankyla	62	65	31	195	58	35	205	53	30	215	48	32	225	40	30	235	35	30	235
Toronto	61	10	30	255	10	30	230	10	25	225	14	25	235	17	25	240	19	25	245
Washington	56	18	22	290	18	30	290	18	40	275	18	40	275	18	42	285	18	43	295
Makerstown	55	18	24	295	18	33	295	18	42	270	18	40	285	18	44	290	19	44	295
Dublin	55	17	27	300	18	37	295	17	44	265	17	40	280	17	46	290	19	45	290
Pawlowak	54	17	30	300	17	40	295	17	46	280	17	44	270	17	48	295	19	46	295
Wilhelmshaven	51	16	25	305	14	28	300	12	27	290	13	27	305	15	26	305	16	25	300
Greenwich	50	16	24	310	14	29	300	12	22	300	12	30	305	14	25	305	16	21	300
Paris	47	15	23	310	14	30	300	13	21	305	12	32	300	15	24	305	16	19	300
Vienna	45	15	25	305	13	31	300	13	20	300	12	32	305	15	27	305	18	21	305
Pola	42	13	27	300	13	32	305	12	20	305	12	32	305	12	32	310	15	27	305
Los Angeles	40	13	30	300	13	34	310	12	23	315	12	34	310	14	27	315	17	31	305
Tiflis	36	12	35	300	13	37	315	14	30	320	15	36	315	15	38	310	17	36	305
Zi-ka-wei	28	9	63	210	8	65	225	9	50	240	10	42	250	11	40	240	13	40	225
Bombay	10	23	35	185	22	35	190	22	40	185	22	46	180	21	43	185	20	40	185
Madras	+ 4	21	35	185	22	32	195	23	37	185	21	45	180	20	40	185	20	38	190
Singapore	- 6	20	35	190	21	33	200	22	35	190	21	43	185	20	35	195	19	37	190
St. Helena	-11	18	32	185	16	32	200	18	35	190	20	40	190	17	33	195	16	35	185
Batavia	-15	16	30	180	14	30	195	16	35	185	18	35	195	13	30	190	12	33	180
Süd Georgien	-30	20	30	70	20	30	65	18	30	65	17	30	60	19	30	50	21	30	45
Cape Horn	-33	20	28	75	20	30	70	18	32	70	19	34	65	21	34	45	22	32	45
Cape Good Hope	-34	20	27	80	20	32	70	19	35	70	19	36	65	20	37	45	23	34	45
Melbourne	-50	18	26	85	18	32	70	17	37	75	19	38	65	20	38	45	21	35	40
Hobarton	-55	16	26	85	16	33	75	15	40	75	17	40	60	20	40	45	21	36	40
Kingua Fjord	+78	93	50	190	92	47	195	87	47	200	82	37	205	58	40	210	66	50	350
Fort Rae	76	94	50	195	100	46	200	90	39	205	78	40	210	62	43	220	64	48	350
Point Barrow	73	98	45	205	106	42	210	88	37	215	65	43	220	43	43	340	50	46	0
Cap Thorsden	71	93	40	210	88	39	215	75	36	225	50	37	230	38	50	345	43	43	10
Jan Mayen	69	90	35	215	75	37	220	65	34	235	40	34	235	28	50	350	40	40	15
Bossekop	65	46	33	230	40	35	230	35	33	245	33	38	225	26	38	330	38	35	20
Sodankyla	62	83	30	240	30	33	245	27	32	250	27	32	310	26	40	285	28	45	80
Toronto	61	21	30	280	26	30	285	26	30	270	26	30	300	26	40	250	25	50	145
Washington	56	19	33	290	21	28	285	24	20	275	27	25	250	29	35	230	23	44	130
Makerstown	55	20	34	295	22	29	285	24	25	275	26	23	245	28	32	225	23	39	125
Dublin	55	21	36	295	23	31	285	25	28	280	26	22	245	26	30	225	24	37	120
Pawlowak	54	22	38	295	24	33	285	26	30	275	27	22	240	26	32	225	24	39	120
Wilhelmshaven	51	18	23	300	23	22	285	26	25	270	27	19	245	27	35	225	26	40	125
Greenwich	50	18	25	300	23	23	285	26	23	275	27	18	245	27	35	225	27	35	125
Paris	47	18	27	305	21	24	300	24	20	285	26	30	245	27	36	225	27	33	130
Vienna	45	25	28	310	22	27	305	24	22	290	26	21	240	27	38	225	27	32	135
Pola	42	19	29	310	21	30	305	24	23	290	26	22	240	27	38	230	27	33	135
Los Angeles	40	19	30	305	21	32	310	25	25	295	27	24	235	26	39	285	26	35	140
Tiflis	36	19	32	295	21	35	295	25	28	285	27	27	235	27	41	230	27	38	140
Zi-ka-wei	28	15	35	210	18	35	220	22	30	260	23	42	230	23	44	225	24	34	145
Bombay	10	22	37	185	23	36	165	23	30	140	24	28	40	34	28	20	43	27	10
Madras	+ 4	22	36	185	23	35	165	23	29	130	24	25	45	35	30	25	44	24	20
Singapore	- 6	19	35	185	20	37	160	24	29	120	27	23	50	37	27	30	45	22	30
St. Helena	-11	18	35	185	20	39	155	24	31	105	28	21	50	35	22	35	45	20	30
Batavia	-15	15	35	180	20	40	150	25	33	90	28	20	55	33	19	40	40	18	35
Süd Georgien	-30	24	32	40	26	28	50	27	30	65	28	35	75	28	30	115	27	35	150
Cape Horn	-33	24	30	45	26	26	55	28	27	70	29	35	75	28	30	120	27	37	150
Cape Good Hope	-34	25	30	45	27	23	55	29	26	70	30	33	80	28	25	120	26	40	150
Melbourne	-50	23	30	40	25	21	55	26	27	70	27	32	75	26	23	115	24	38	145
Hobarton	-55	22	32	40	25	20	60	28	30	65	27	30	75	26	25	110	23	35	140

TABLE 19.—Deflecting vectors of the equatorial electro-magnetic field—Continued.

[Measured on the globe model.]

[s = units fifth decimal C. G. S.; α = positive below horizon; β = in azimuth N. W. S. E.]

Station.	Mag. lat.	Noon.			1 p. m.			2 p. m.			3 p. m.			4 p. m.			5 p. m.		
		s	α	β	s	α	β	s	α	β	s	α	β	s	α	β	s	α	β
Kinqua Fjord...	+78	74	-51	358	85	-52	0	93	-53	10	94	-50	15	93	-47	15	90	-44	20
Fort Rae...	76	72	-48	0	75	-49	10	80	-50	15	89	-48	20	94	-45	20	90	-41	25
Point Barrow...	73	63	-46	5	68	-45	15	76	-45	20	87	-42	25	94	-42	25	95	-38	30
Cap Thordsen...	71	57	-42	15	68	-42	20	76	-40	20	90	-39	25	100	-38	25	97	-34	30
Jan Mayen...	69	54	-39	20	62	-39	25	75	-37	25	91	-36	25	102	-34	25	94	-30	30
Bossekop...	65	48	-36	30	56	-36	35	70	-35	35	80	-33	30	84	-33	30	83	-30	30
Sedankyla...	62	27	-35	75	35	-34	60	44	-30	55	52	-30	45	58	-32	40	62	-32	35
Toronto...	61	26	-35	120	27	-30	110	26	-25	70	26	-28	60	24	-30	55	18	-40	40
Washington...	56	30	-35	115	31	-28	105	29	-24	60	27	-23	70	25	-40	50	23	-42	45
Makerstown...	55	30	-32	115	31	-24	100	29	-21	90	27	-24	75	26	-42	60	21	-44	50
Dublin...	55	32	-34	110	31	-22	100	29	-18	93	27	-24	80	26	-40	65	24	-44	55
Pawlowsk...	54	32	-35	110	32	-20	100	30	-17	90	27	-22	85	25	-39	70	23	-42	65
Wilhelmshaven...	51	35	-37	115	34	-20	105	30	-18	85	25	-20	95	21	-40	80	19	-42	75
Greenwich...	50	37	-35	110	36	-20	100	33	-19	95	25	-19	95	21	-40	80	18	-45	85
Paris...	47	38	-35	105	36	-21	100	33	-20	95	26	-18	95	22	-38	80	18	-44	90
Vienna...	45	36	-33	105	35	-22	100	30	-22	95	26	-18	100	22	-37	85	18	-42	90
Pola...	42	35	-34	105	33	-25	100	30	-25	95	25	-20	95	21	-37	90	17	-45	95
Los Angeles...	40	35	-35	105	33	-30	100	30	-26	95	25	-22	95	21	-38	90	17	-47	100
Tiflis...	36	35	-37	100	33	-36	90	30	-29	85	24	-27	90	20	-42	110	16	-50	110
Zi-ka-wei...	28	27	-42	75	26	-45	45	23	-30	65	20	-45	50	13	-48	115	15	-54	140
Bombay...	10	44	-27	15	40	-33	345	37	-30	340	19	-52	315	16	-30	225	15	-35	195
Madras...	+ 4	44	-28	15	40	-32	345	35	-28	340	18	-30	305	17	-32	220	16	-30	195
Singapore...	- 6	44	-30	15	40	-30	345	33	-26	335	17	-28	300	17	-32	220	17	-25	200
St. Helena...	-11	43	-32	10	40	-30	340	32	-25	335	15	-28	295	16	-30	220	16	-20	200
Batavia...	-15	41	-35	10	38	-30	340	32	-25	330	15	-28	290	16	-30	215	17	-15	200
Sid Georgien...	-30	30	-45	220	31	-40	230	32	-35	240	32	-30	260	28	-30	270	24	-40	265
Cape Horn...	-33	30	-43	225	32	-38	230	32	-36	245	30	-35	260	29	-30	275	25	-40	270
Cape Good Hope...	-34	28	-40	210	30	-35	230	30	-37	250	30	-30	260	28	-25	275	25	-38	275
Melbourne...	-50	27	-40	230	32	-33	235	30	-38	260	30	-30	265	27	-20	275	24	-37	280
Hobarton...	-55	25	-35	230	33	-35	240	28	-37	265	30	-35	265	26	-35	280	21	-40	280

Station.	Mag. lat.	6 p. m.			7 p. m.			8 p. m.			9 p. m.			10 p. m.			11 p. m.		
		s	α	β	s	α	β	s	α	β	s	α	β	s	α	β	s	α	β
Kinqua Fjord...	+78	80	-42	20	68	-40	25	58	-35	30	55	-32	30	52	-28	30	44	-38	135
Fort Rae...	76	82	-40	25	70	-37	25	60	-34	30	56	-31	40	54	-24	40	52	-40	140
Point Barrow...	73	83	-37	30	72	-36	30	62	-36	35	57	-27	50	54	-20	45	52	-42	145
Cap Thordsen...	71	86	-36	30	70	-34	30	60	-39	40	55	-23	60	55	-25	130	56	-40	150
Jan Mayen...	69	84	-36	30	60	-33	35	57	-33	45	53	-20	65	53	-30	140	57	-38	160
Bossekop...	65	72	-35	35	50	-30	40	45	-27	45	43	-28	140	44	-30	150	50	-34	180
Sedankyla...	62	60	-34	35	42	-25	40	37	-22	50	38	-28	145	40	-30	155	47	-30	185
Toronto...	61	14	-43	30	10	-44	50	9	-30	45	9	-35	330	8	-28	200	7	-20	270
Washington...	56	21	-58	25	20	-56	340	19	-34	310	18	-40	300	17	-24	300	17	-24	295
Makerstown...	55	24	-60	20	22	-53	330	20	-37	305	18	-37	295	17	-22	295	16	-22	300
Dublin...	55	24	-58	20	21	-48	325	20	-40	305	19	-38	290	18	-22	290	16	-20	300
Pawlowsk...	54	22	-56	15	21	-45	320	19	-40	310	18	-38	290	17	-27	295	16	-20	300
Wilhelmshaven...	51	19	-54	25	19	-40	315	19	-42	310	19	-39	300	19	-30	300	17	-32	305
Greenwich...	50	18	-54	30	19	-38	320	19	-44	310	18	-37	305	19	-35	305	18	-30	305
Paris...	47	17	-56	35	17	-38	325	17	-46	315	17	-35	310	17	-38	305	17	-27	305
Vienna...	45	16	-55	45	16	-40	335	15	-42	310	14	-38	305	15	-39	300	15	-33	305
Pola...	42	13	-56	55	11	-45	50	10	-40	295	10	-38	300	9	-41	295	8	-45	300
Los Angeles...	40	12	-58	115	11	-47	105	9	-42	140	9	-40	225	9	-45	290	8	-48	295
Tiflis...	36	12	-60	125	12	-44	140	10	-43	150	9	-45	250	8	-53	230	8	-50	240
Zi-ka-wei...	28	16	-27	155	18	-40	160	16	-40	175	10	-50	185	10	-60	180	9	-55	180
Bombay...	10	17	-27	195	19	-30	180	21	-33	180	21	-35	180	20	-33	180	20	-30	185
Madras...	+ 4	18	-24	195	21	-30	180	22	-30	180	22	-33	180	23	-30	180	24	-30	185
Singapore...	- 6	19	-22	190	21	-30	185	23	-28	180	24	-30	180	24	-27	185	24	-28	190
St. Helena...	-11	19	-20	190	22	-30	185	24	-28	185	25	-27	175	24	-25	185	24	-25	185
Batavia...	-15	20	-18	190	23	-30	185	23	-30	185	24	-25	175	24	-25	190	24	-25	185
Sid Georgien...	-30	21	-40	255	18	-45	215	18	-50	185	20	-50	120	20	-45	100	20	-35	90
Cape Horn...	-33	21	-40	255	18	-45	225	18	-46	185	18	-48	125	18	-40	100	18	-35	90
Cape Good Hope...	-34	20	-40	260	18	-45	240	18	-45	190	17	-45	190	18	-40	100	18	-35	85
Melbourne...	-50	20	-40	270	17	-45	300	16	-45	350	16	-45	55	17	-40	70	18	-35	75
Hobarton...	-55	19	-40	280	16	-44	310	16	-46	350	16	-45	65	17	-40	75	17	-38	80

CHART 14.—Deflecting forces of the electro-magnetic field with sun on central meridian.

β = Azimuth counted. 0° = north, 90° west, 180° south, 270° east. α = Altitude counted, + below surface, - above surface. s = Length of the deflecting vector force at given place and time. Red lines = forces entering the earth. Blue lines = forces emerging from the earth.

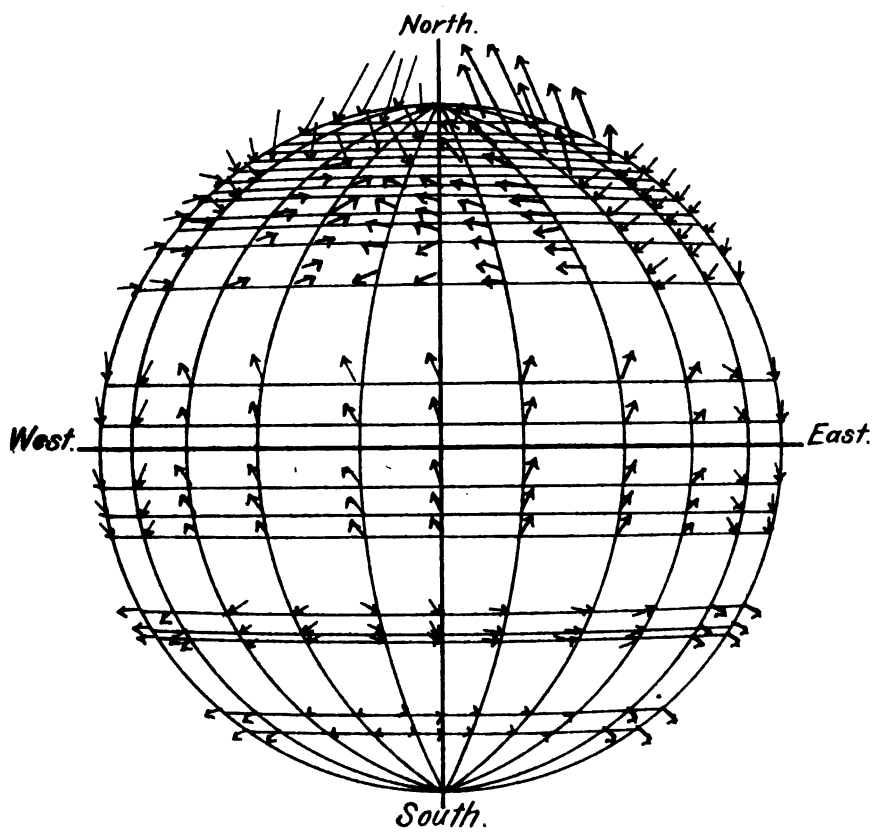


Chart 14.

Chart 14 shows the vectors of the model looked at from the sun and along its radiant lines. Chart 15 shows the same model looking down upon the north magnetic pole. The orientation and position of the stations is shown by the precepts on the diagrams. Chart 16 gives a scheme of the vectors in both hemispheres. It is once more recommended that a similar model be constructed by students who desire to have a fitting idea of this magnetic field.

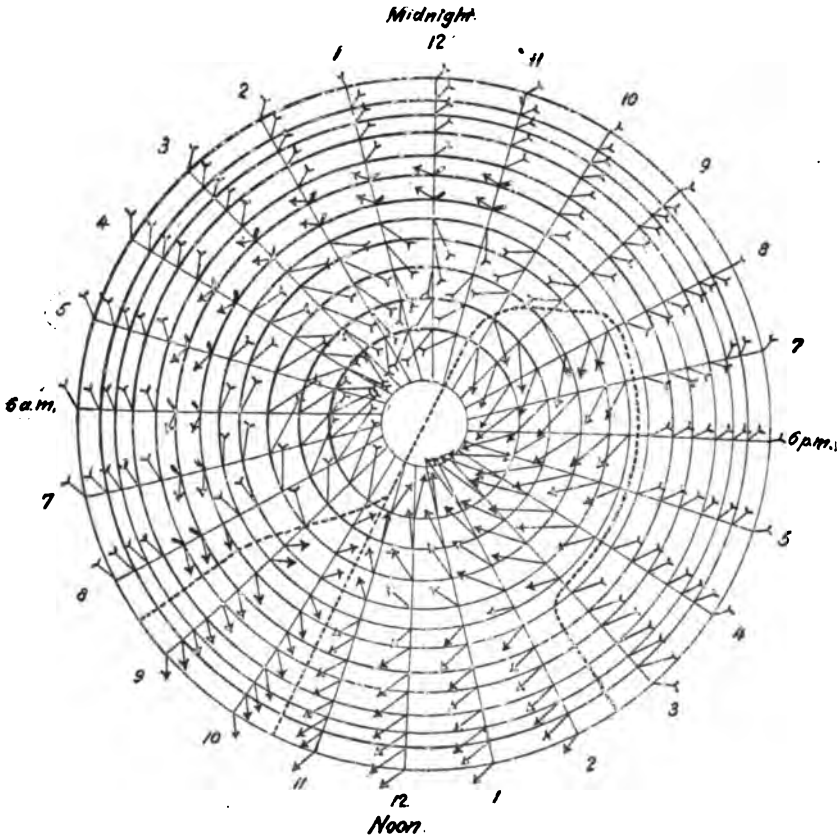


CHART 15.—Deflecting forces of the electro-magnetic field, north magnetic hemisphere.

DESCRIPTION OF THE FORCES OF THIS MAGNETIC SYSTEM.

An inspection of the model shows that it is constructed under these controlling conditions, (1) couples, (2) magnetic refraction, (3) a permeable shell. There are three distinct couples: (1) That in the polar cap, with axis in northern hemisphere on the 4 o'clock meridian. The counterpart in the southern hemisphere is not in evidence for lack of observations, but symmetry requires its existence. The vectors are strong, and vary from 0.00100 C. G. S. to .00040 C. G. S., the long ones spreading out and entering the cap on each side at 4 a. m., but

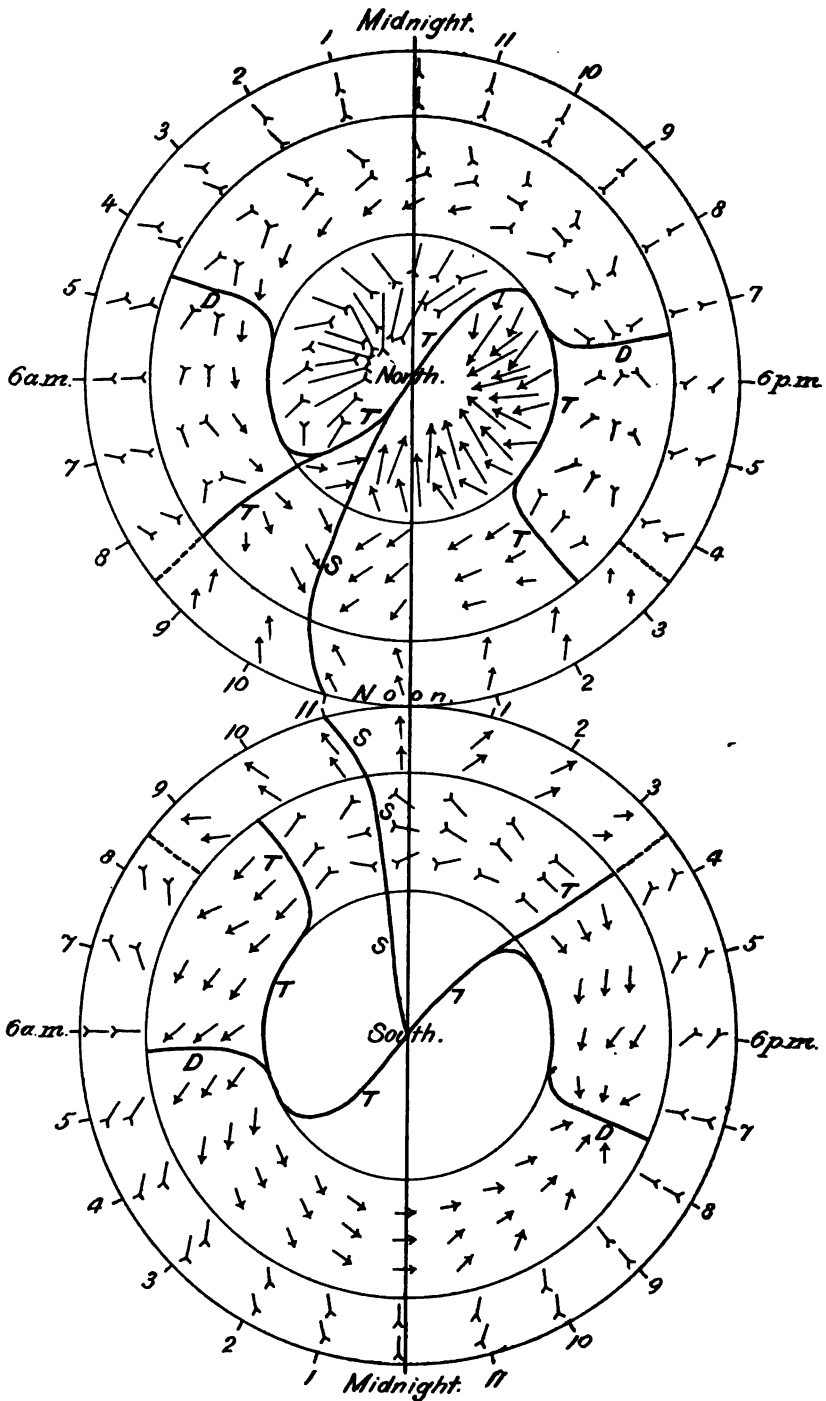


CHART 16.—Scheme of the directions of the deflecting forces causing the diurnal variations.

concentrating and emerging on the opposite side at 4 p. m. Along the 10 a. m. and 10 p. m. meridians the lines evidently pass through the cap. Probably all the entering lines are transmitted within the cap, but this is not so certain, as some lines may perhaps pass through the shell from north to south, like the lines of the polar field previously described. (2) The second couple is in the midlatitude zones, with vectors toward the sun in the northern and away from the sun in the southern hemisphere. (Chart 14.) These vectors do not converge on the noon meridian, but at 10.30 a. m., and they represent a sheet-system asymmetrically disposed to that plane on the illuminated side of the earth. Whether this is a true lag angle caused by rotation or a displacement due to the fact that the magnetic lines seek the coldest surface regions consistent with the balance of the total system, and is therefore partly a meteorological phenomenon, it is not easy to say. The corresponding plane of divergence of the sheets in the northern hemisphere is at 6.30 p. m., and in the southern hemisphere at 8 p. m. The southern hemisphere seems to be in some respects twisted about one hour in the direction of rotation relatively to the northern. (3) The third couple is in the tropical zone, with vectors emerging northward on the sun side and entering southward on the dark side of the earth. All these couples are consistent with the view that the earth, having its positive magnetism south and negative north, is placed in a field of force diminishing in strength from the sun outward, because the southern geographical hemisphere is repelled and the northern attracted. This would seem to be proof positive that the electro-magnetic field of solar radiation is capable of acting like a static field, and is one more instance of the breaking down of the distinction usually maintained, that the nature of the static and dynamic lines of magnetic force is essentially different. So-called static lines are probably rotating vortices, the angular velocity being unknown, but great. Dynamic radiant lines are quite certainly transverse vibrations of enormous frequency, but both are essentially dynamic conditions of ether motion and should be treated from this point of view.

The phenomena of refraction is clearly seen to be a characteristic of this field of force. Thus across the north polar region there is a line of tangency where the vertical component disappears, on the west side of which the forces enter and on the east side emerge. This line extends southward between 8 a. m. and 9 a. m. to the southern hemisphere, but reverses the relative entry and emergence of the vectors. It returns between the 2 p. m. and 3 p. m. meridians, having, no doubt, crossed the south pole with its counterpart vectors. It makes a turn along the sixtieth north parallel just under the aurora belt till it joins its lines over the polar regions (Chart 15, dotted lines). Between 10 a. m. and 11 a. m. the declination component vanishes, when H and V are at a maximum. This line also passes from the north pole to the south pole, but has a tendency to become 11 a. m. or 11.30 a. m. in the southern hemisphere. It does not appear on the dark side of the earth.

There is a belt including the stations Washington, Makerstown, Dublin, Pawlowsk, near magnetic north latitude 50° extending from midnight to 6 a. m., where the sign of the vertical angle is not decisively determined. The impression from the neighboring stations on the model is that it should be +, that is entering the surface; but from the computations it is probably —, as given. There is a transition from one sheet to the other at this latitude, and its effect may, in fact, be to make the angle α negative along a narrow zone. Further attention should be paid to this region. It may be remarked that usually the passage from one system of couples to another is accompanied by small values of s , large values of α , and rapidly changing values of β .

The distribution of any system of outside forces is determined not only by the permeability of the material but by its shape as well, because a path that is limited to a narrow region inside necessarily constrains the outside force to take up such curves in the ether as will carry them to the surface at angles consistent with the index of magnetic refraction and the interior path. Hence we have in the case of a shell a system of forces (1) compelled to go through a thin cap at the poles, (2) around thin zones in middle latitudes, and (3) up and down through a thin zone in the equatorial regions. This explanation is entirely consistent with the results of the discussion of the polar magnetic field, on the view that the sunlight field has the power to act like an ordinary magnetic field as usually understood. Recalling now the conclusions of the preceding chapter, where it was indicated that we have three component fields of magnetic force to consider, namely, (1) the field from the earth's magnetization, (2) the impressed field from the normal polar magnetism of the sun, (3) the variations of these fields, the former in secular and the latter in short periods, we have yet to add the field (4) just now derived from the equatorial solar radiation. We thus advance to another degree of complication, when discussing the action of induction from vibrations of great frequency, from the motion of the mass of the earth within two outside fields, from convection currents of the atmosphere, from degeneration of all waves into Joule's heat, from atmospheric electricity, and even other types of energy.

At this place many academic questions can be raised, resulting from old theories, or from lack of understanding of the full consequences of the evidence here brought forward, but it must be remembered that discussions involving the conflict of old and new views only serve to obscure the question, unless it can be shown by fair criticism that the treatment of the observations is in some way incorrect. If the evidence is accepted as sound, then portions of the theories regarding the origin of terrestrial magnetic forces which are now held must be abandoned or else modified to meet the facts brought forward. For my part, after patient consideration of all the data, I see no reason for not accepting the views substantially as explained in my papers pertaining to these subjects.

CHANGE OF THE ENTIRE VECTOR SYSTEM IN LATITUDE WITH THE
SUN'S DECLINATION.

As a proof that the vector system here attributed to the electro-magnetic field has in reality that origin, there is one fact which can not be reproduced in full in this abstract. In studying the vectors from month to month (see Jan Mayen) it is found that as the sun changes its declination the entire magnetic system follows it in both hemispheres. At each station there occurs a variation in the components, such as has been studied in the annual variations, which yet constantly refers the couples to an axis always pointing to the sun. In no other way could this occur than as a consequence of the changing aspect of the earth's field in the external field, brought about by the orbital motion of the earth around the sun. Those who seek, therefore, to account for the earth's magnetic field by atmospheric currents of convection alone, omitting impressed external fields, must show that such meteorological air currents exist as would produce not only the distribution described in the preceding but also in the present chapters. It is much more probable that certain meteorological effects must be ascribed to the action of the external fields, than that the fields themselves should be the effects of the movements of the atmosphere in convection currents.

CHAPTER 5.

SOME RELATIONS BETWEEN THE VARIATIONS OF THE TERRESTRIAL MAGNETIC FIELD AND THE METEOROLOGICAL ELEMENTS.

METHOD FOLLOWED IN COMPARING MAGNETIC AND METEOROLOGICAL DATA.

We will now briefly sketch the process employed in our own investigations, in an attempt to bring this entire subject to a more definite conclusion than has heretofore been secured. The data accessible in the publications of previous papers, such as van Bebbber's, will not be referred to any further, since our effort has been to secure new evidence, especially pertaining to the United States. The conclusions reached have been based upon the careful discussion of a large mass of material, involving slow approximations and the repeated traversing the same data several times, as one difficulty after the other was cleared away. Even as matters now stand, it will require further consideration of the data in order to reach a perfect exposition of the several parts of this complex problem. Having developed an ephemeris depending upon the periodic variation of the earth's magnetic field, this was laid at the basis of further progress in the analysis, the object being simply to discover the fundamental normal curve representing the impressed solar magnetic field, and to detect the occurrence of the same periodicity in the meteorological changes of the atmosphere, if such actually exists. The process of computing the horizontal component σ , described above in Chapter 2, was extended to five European stations, for the years 1878 to 1889 inclusive. Since the ratio of the component σ to the total force s is for these stations nearly constant on the average, and since the variations of H and D are more accurately measured than those of V , the compilation of magnetic data was limited to the component σ . In Table 20 is exhibited as specimens for two years, 1878 and 1882, the observed mean values of σ . Each entry is the mean of the computed σ at Greenwich, Vienna, Prague, Pawlowsk, Tiflis, when these stations were available. Thus + 46 means that + 0.000046 is the mean σ for January 8, 1878, in C. G. S. units for five stations. In order that no bias might attach itself to the first derived form of the normal curve, it was assumed that, if certain days of the period possess an excess of force over others, this would be declared by an increase of the absolute numerical values on such days. The

mean of these tabular quantities was therefore taken without regard to sign; and it is shown on the line marked "mean," for each year. Afterwards these numbers were added algebraically, using all the signs. Then the series of annual means, 1878-1889, was collected into one table, and the final mean taken for the entire interval. These numbers were plotted into a curve of relative values, and it gave substantially the form presented in chapter 1, chart 9, which is the normal type finally settled upon, except that the minor crest at day 8 was lacking, and the double crest from days 17 to 19 was merged into one sweep.

TABLE 20.—Variations of the horizontal force ϕ , for 1878 and 1882.

[Units sixth decimal, C. G. S.]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1878.													
Jan. 8.50	+ 46	+ 36	+ 46	- 73	- 59	- 64	- 45	- 33	+ 65	+ 55	+ 52	+ 39	+ 67
Feb. 4.18	+ 51	+ 42	- 61	- 74	- 50	- 27	- 26	- 45	- 37	+ 54	+ 85	+ 47	+ 59
Mar. 2.86	+ 39	+ 64	+ 59	+ 55	+ 71	+ 70	+ 45	+ 41	+ 26	- 56	+ 76	+ 68	+ 67
Apr. 29.54	+ 32	+ 36	- 25	+ 45	+ 88	- 90	- 26	+ 38	+ 25	+ 52	+ 69	+ 71	+ 54
May 25.22	- 71	+ 56	+ 73	- 74	- 36	- 61	+ 55	- 60	- 64	+ 43	- 77	+ 66	+ 90
June 21.90	- 45	+ 29	+ 61	- 50	- 56	- 49	+ 39	+ 37	+ 53	+ 42	+ 39	+ 48	+ 66
July 17.58	+ 96	+ 90	+ 59	+ 77	+ 84	- 68	- 79	- 78	- 98	- 71	+ 83	+ 120	+ 72
Aug. 14.26	- 74	- 21	- 36	- 93	- 82	- 106	- 76	+ 83	+ 53	+ 51	- 42	- 50	+ 74
Sept. 9.94	- 116	- 52	- 48	- 35	- 47	- 33	- 37	+ 37	+ 49	+ 29	+ 77	+ 60	+ 45
Oct. 5.92	- 63	- 54	- 59	- 60	- 72	- 78	+ 61	+ 48	+ 37	- 39	+ 40	+ 84	+ 83
Nov. 2.30	- 71	- 55	- 75	- 67	+ 82	- 86	+ 62	- 53	+ 44	+ 38	+ 27	+ 57	+ 31
Dec. 28.98	- 61	+ 45	+ 83	+ 33	- 106	- 109	+ 90	- 172	- 156	- 105	- 97	- 121	- 99
Jan. 24.66	+ 120	+ 86	+ 150	+ 169	+ 146	+ 111	+ 115	- 119	- 102	+ 49	+ 67	- 41	- 69
Feb. 21.32	- 29	+ 41	+ 49	+ 52	- 42	+ 55	+ 50	+ 42	+ 58	+ 50	- 96	- 77	+ 84
Mean	65	50	63	68	73	72	58	63	62	52	96	67	69
D	-218	-125	-207	-117	+ 51	-221	+ 60	+ 70	+ 155	+ 80	+ 213	+ 272	+ 151
I	+214	+468	+545	+ 22	-131	-248	+168	-304	-202	+118	+ 90	+ 96	+411
1882.													
Jan. 14.90	- 51	- 44	- 71	+ 31	+ 56	-158	-195	- 82	- 59	+ 41	- 78	+ 61	+ 85
Feb. 10.58	- 85	-134	+ 87	+ 59	- 59	+ 45	- 61	+ 96	- 64	+ 81	-213	-178	-125
Mar. 9.26	-188	-106	-104	+ 55	+ 77	- 74	+ 57	- 89	+ 56	+102	+ 85	-139	-106
Apr. 4.94	+ 48	+ 82	- 46	+ 81	+ 92	+ 76	+ 146	-184	+196	+279	+120	+ 89	+155
May 1.62	- 52	-121	+124	+ 76	+ 58	+ 60	+ 80	+ 66	+155	+178	+135	+ 71	+ 62
June 28.30	- 92	- 80	+ 69	+ 80	+ 79	- 73	+ 87	-106	+155	+150	+118	+141	+140
July 23.98	- 79	-165	-314	-160	-182	-124	-124	- 90	- 51	+ 86	+ 72	+141	+ 42
Aug. 20.66	- 71	+181	+115	+120	+144	+116	-130	- 85	+ 86	+160	+119	-217	-233
Sept. 16.24	- 74	- 47	+ 59	+ 81	+ 76	- 87	- 71	- 56	+121	+108	+ 63	+ 78	- 82
Oct. 12.02	+ 73	- 82	+ 71	+ 82	- 72	+ 84	+ 81	+102	+ 70	+ 54	+ 67	+ 83	+291
Nov. 8.70	-100	- 66	- 34	+ 56	+ 54	+ 95	+ 80	- 67	+103	+112	+106	+130	+169
Dec. 4.38	+186	+234	+195	+163	+147	+105	+204	+265	- 86	-356	-135	+147	+151
Jan. 1.06	+ 98	+ 96	+151	+114	- 77	+118	+124	+141	+106	+116	+120	+ 55	- 80
Feb. 27.74	+ 64	+ 59	+ 82	+ 81	+ 82	+ 47	+ 41	+ 56	+100	+ 96	- 84	- 66	- 64
Mean	90	107	103	89	90	90	106	105	101	127	106	114	121
D	-213	-316	+ 70	+445	-358	+130	- 68	- 87	+329	+594	- 51	- 31	+ 76
I	+180	+164	-450	-474	-415	+274	+387	+571	+561	+690	+539	+437	+397

TABLE 20.—Variations of the horizontal force ϕ , for 1878 and 1882.

[Units sixth decimal, C. G. S.]

14	15	16	17	18	19	20	21	22	23	24	25	26	27	M. P. T.
+ 139	+ 140	+ 51	-197	- 95	- 60	- 41	- 20	- 51	- 37	- 32	- 64	- 51	+ 48	I
+ 51	+ 49	+ 54	+ 60	+ 28	+ 48	- 97	- 94	- 76	-118	- 48	- 29	+ 83	.....	I
- 79	- 77	-103	- 92	+ 80	+ 57	+ 47	+ 63	+ 53	+ 40	- 41	- 35	+ 88	+ 60	I
+ 66	+ 54	+ 74	+ 85	+104	+ 56	+ 71	+ 86	- 71	- 29	- 47	- 42	- 24	- 43	I
+ 55	+ 83	+ 71	+ 56	+ 93	+ 67	-133	-112	- 99	- 66	- 78	- 69	- 49	.....	D
-162	-198	- 98	- 91	+ 47	+ 81	+ 87	+ 58	+ 46	+ 57	+ 83	+100	+ 84	+111	I
+ 44	+ 52	+ 39	+ 43	+ 49	+ 53	+116	+ 72	+ 50	- 26	- 52	- 44	- 31	- 56	I
+ 17	+ 28	- 58	- 41	+ 49	+ 37	+ 75	+ 73	+ 46	- 32	- 47	- 79	-113	.....	I
+ 43	+ 23	+ 48	+ 73	+ 50	+ 36	- 44	- 44	+ 57	- 37	- 58	- 58	+ 51	+ 50	D
+ 67	+ 40	+ 58	+ 60	+ 83	- 99	+ 58	+ 39	- 68	+ 22	+ 27	- 73	- 57	- 39	D
- 31	- 11	+ 45	- 92	- 87	- 91	- 74	+ 88	+ 81	+ 47	+ 24	+ 55	+ 53	.....	D
- 95	-102	-100	- 89	+ 56	+ 85	- 63	- 69	+ 63	+ 40	- 58	+ 60	- 42	+ 49	I
- 58	+ 29	+ 41	+ 33	+ 45	+ 86	- 82	- 42	- 35	+ 40	+ 61	- 45	- 34	- 58	I
+ 68	+ 79	+ 96	+101	+ 87	+ 97	+ 90	+ 43	+ 55	+115	+132	+103	+124	+ 55	I
70	69	67	80	68	68	77	65	61	50	56	61	63	57	64
+ 145	+ 106	+225	+126	+150	- 98	-131	- 3	- 1	+ 3	- 54	-118	+ 23	- 32	.....
- 20	+ 83	- 7	- 31	+341	+ 546	- 1	- 38	- 74	+ 19	- 80	-102	+ 59	+209	.....
+ 77	+ 99	+117	+ 81	+113	+ 122	-163	+ 98	+103	+ 83	+ 88	-143	-173	- 92	D
+ 71	+ 61	+ 58	+ 96	+ 76	+ 39	+ 59	+106	+ 51	+ 47	- 25	- 32	+ 51	+ 25	D
+ 120	+ 90	+ 86	+124	+175	+ 37	+ 93	+158	+125	+160	+164	+146	+172	.....	D
-1044	- 566	-209	-378	-349	- 236	-131	-188	+ 64	+ 62	+ 82	+ 97	+104	+ 61	I
-172	-157	-110	+ 71	- 89	- 53	+ 92	+ 61	- 89	- 63	+ 52	+ 69	+ 78	+ 78	I
+ 144	+173	+103	+ 63	+143	-172	-145	-154	- 53	- 80	+126	-148	-101	.....	I
+ 86	+ 74	+ 63	-137	- 48	- 43	+ 67	- 62	- 58	+101	+139	-109	+ 92	+ 76	I
-118	- 56	- 92	-255	-153	-148	- 95	- 80	-121	- 50	+112	+106	+ 73	+ 99	I
+ 78	+ 74	+113	+160	+126	+ 85	+ 64	-180	+ 49	+ 27	+ 24	+ 56	+ 56	+ 54	D
- 211	- 56	- 72	- 65	- 84	+ 78	+258	+235	-400	-132	-375	-180	.....	.....	D
+ 180	+144	+ 47	+ 87	- 98	- 61	+ 69	- 97	- 85	+ 60	+130	+170	+244	+214	D
-248	-1135	-274	-964	-650	-282	-141	- 75	-164	-142	-101	- 90	+104	+134	I
+ 94	+144	-177	- 76	- 96	-126	-267	-345	-255	-101	-107	- 50	+ 66	.....	I
- 42	+ 49	+ 47	+ 68	+ 58	+ 49	+ 52	+ 45	- 62	+ 45	+ 55	- 82	- 61	+ 89	D
126	120	105	137	124	111	119	124	109	91	95	111	111	92	108
+ 273	+ 461	+396	+542	+366	+ 399	+424	+365	- 69	+172	+304	-135	+106	+290	.....
- 464	- 322	-672	-829	-713	-1028	-603	-698	-671	-273	+302	-125	+419	+448	.....

Next it was sought to find out whether there is a similar curve in the several meteorological elements, and the data derived from the pressure and temperature was compiled on precisely the same plan for a series of years; certain rough curves, bearing a striking resemblance to the type curve, emerged as the result of almost every application of the ephemeris to the data of meteorological observations. This crude result was presented in a paper read before the International Meteorological Congress, Chicago, August, 1893. Experience with this curve in its application to individual periods of the ephemeris, gradually strengthened the conviction that the tendency to recur was continuous, and not confined merely to the mean value of a long tabulation, as might perhaps have been objected was the case. The pursuit of these individual repetitions of the type curve, amid all the loosely constructed irregularities constituting the recorded meteorological changes, has been a most laborious and tantalizing task, and yet one absolutely necessary to perform, if a definite result is demanded. It is necessary here to omit a large block of material in the form of curves which represent the observations.

One fact greatly tends to obstruct the detection of the normal curve in the meteorological field of middle latitudes, namely, the rapid eastward drift of the atmosphere, and the confused circulation attending the passage of the anticyclones and the cyclones over the United States. In order to study the eastward movement carefully, and to discover the regions responding most sensitively to this impressed magnetic impulse, the territory of the United States east of the Rocky Mountain crest was divided into groups, as described in the paper, "Inversion of temperatures" (Amer. Journ. Sci., Dec., 1894). The mean temperature of the reporting Weather Bureau stations, at the 8 a. m. and the 8 p. m. observations, for each group, was plotted on a scale of 1 cm. per day, the broken line joining the ordinates representing the actual variation of the mean temperature recorded in that region. Similarly the pressures were reduced to a representative line. The diurnal variations, the rapid changes attending the passage of "highs" and "lows," also the slower changes pertaining to seasonal conditions, are thus graphically displayed in a form suitable for critical examination. Beginning with the extreme northwest—that is, the western Canadian stations north of Montana—the dates of the magnetic ephemeris were superposed upon the common calendar dates and a line was drawn through the successive groups, sloped forward just enough to display the average advance of weather conditions to the east and south in that district, so that the individual crest of temperature or pressure continues at the same distance from this initial line. Thus the periods of the ephemeris may be applied to any district of the United States, and they will be correct to the degree in which the conditions propagated eastward represent the original form of the curve in the northwest. It was found by matching the normal curve with these graphic

lines that there is a definite recurrence in the meteorological changes. The long sweep of the curve, as well as the minor crests, greatly assisted the matching of the curves. It was perceived that the succession of changes on the eastern slope of the mountains, to the north of Montana, lying under the auroral belt, was approximately of the same type as the normal curve, in spite of many irregularities. This is also true of the Dakotas, allowing one day to elapse on the ephemeris. Such comparison of the conditions of the weather maps with the type curve has been practised with persistency from day to day for several years, and the agreement seems to continue as regularly now as when this work began. We have five or six complete rolls of these temperature and pressure changes, each roll covering one year.

THE PHENOMENON OF INVERSION OF THE NORMAL CURVE.

Unfortunately for the rapid progress of the investigation, the conclusion gradually shaped itself that the normal curve had a tendency to invert on its long axis during certain periods. An intercomparison of the periods presented such evidence that it was not possible to put this idea aside. The sequence of the inversion was at first apparently lawless, so that no cause or reason for it could be readily assigned. The detection of the law of inversion has, however, served to place the entire subject of direct solar magnetic action in a new aspect, and greatly adds to the probability of the truth of that theory. The looseness of the individual curves relatively to the normal form is evidently due to the feeble impressed magnetic force operating on the atmosphere; to the fact that the convectional circulation overpowers the magnetic impulse at times; and to the wide and unsteady deviation of the solar output itself from its mean normal type. If a perfect match between the normal and the observed curves is demanded, it can be procured only by the existence of perfect conformity on the part of the sun to the normal type in each period, and also on the condition *that the magnetic force is alone responsible for the observed meteorological impulses*, which of course is not the case, because this would be equivalent to annihilating the effect of the temperature gradient between the equator and the poles. All that we claim exists is, an impulse derived from the magnetic field, which tends to make the convectional system of atmospheric currents culminate in "highs" and "lows," respectively, on the dates of the excess or defect of the solar magnetic force by means of the well-known law of physics, that cooling the medium containing magnetic force increases its strength, and its converse, that an increase of magnetic force cools the medium. The cooling of the air in a stronger magnetic field tends to precipitate "highs" on the northwest of the American continent, in conjunction with the mean trend of the seasonal isobars. The relaxing of this tendency in a weaker magnetic field allows the "lows" from the North Pacific to work in upon the continent or else to form along the eastern edge of the mountain divide, as has

been shown to be the case in the local origination of two-thirds of the United States storms. (Bulletin No. 21, Storms and Storm Tracks.) This view calls for no unusual physical conditions, and it is believed to represent simply the facts observed in connection with the formation of the current American weather.

DISCOVERY OF THE LAW OF INVERSION.

A process will now be briefly summarized that has cost much time and labor in the effort to discover the law of the inversion of the normal-type curve, leaving the explanation of the reason of the same for the following chapter. In the Table 21 of direct and inverse types appear four systems, marked T, M T, M P T, and M, respectively. M stands for European magnetic horizontal component σ , P for barometric pressure in the northwest of the United States, T for temperature in the same districts. M is the mean value of 5 stations, P of 10 stations, and T of 10 stations usually, the latter being generally the Dakota or Upper Missouri Valley stations. In the case of the magnetic system, preceding 1878 the horizontal force alone was employed—that is, without composition with the declination. Several stations, when available, were taken simultaneously and in widely separated latitudes, as Toronto, Greenwich, St. Helena, Singapore, Cape of Good Hope, and Hobarton. The values, derived directly from the published reports of magnetic observations in mean groups, or singly for the earlier years, were transferred to form graphic traces, distributed in the periods of the 26.68-day ephemeris. For an example, the periods beginning August 3.58, 1845, and November 18.30, 1845, are shown on charts 17, 18. The curves are made by extracting the values from the volumes whose pages are indicated just beneath the names of the stations, and are plotted on such a scale as will reduce them to the same amplitude, the scale being placed at the beginning of each curve. Underneath the group is found the type curve from chart 9. Now, two facts are readily seen—that all these curves rise and fall together, and that therefore the horizontal force increases and diminishes simultaneously over the entire earth, which really proves the existence of an external magnetic field in composition with the normal terrestrial field. The other fact is that the first period apparently agrees with the direct type and the second with the inverse type of the normal periodic curve.

CHART 17.—Variation of the horizontal force. Period beginning August 3.58, 1845. Illustrates a direct type period.

CHART 18.—Variation of the horizontal force. Period beginning November 18.30, 1845. Illustrates an inverse type period.

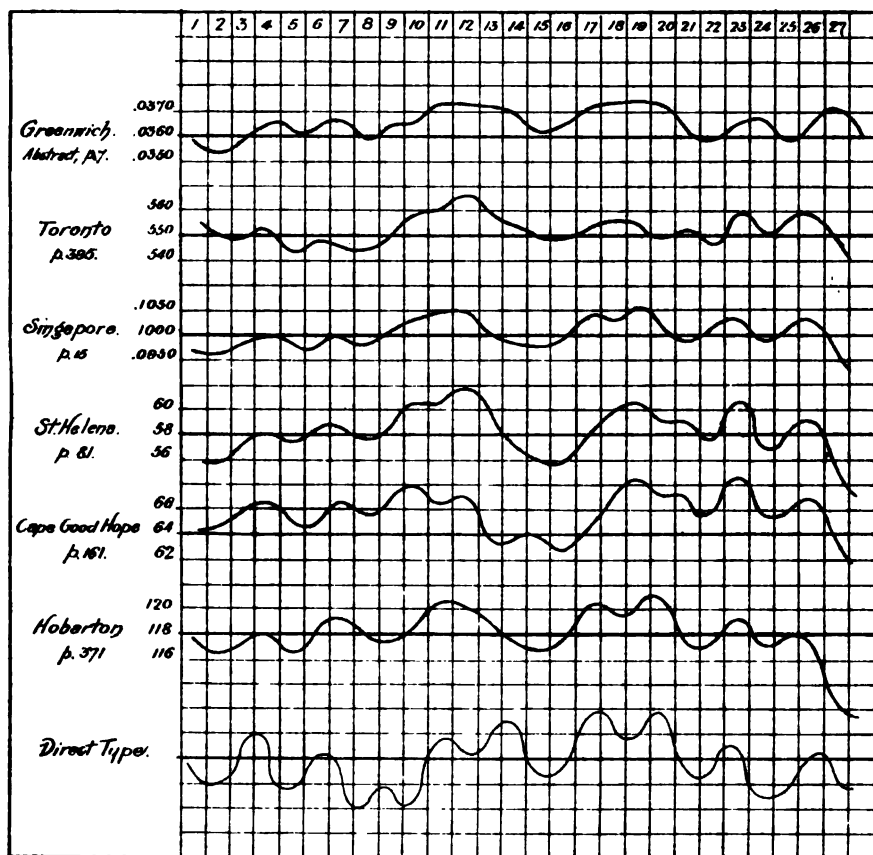


Chart XVII.

TABLE 21.—*Direct and inverse types, found by trials.*

T. SYSTEM.

Periods.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1878.....	D	I	I	I	I	D	D	I	D	D	D	I	D	D
1879.....	I	I	D	I	I	I	D	D	D	D	D	D	D	D
1880.....	D	D	D	I	I	I	I	I	D	D	D	D	I	D
1881.....	D	D	I	I	I	I	D	D	D	I	I	I	D	I
1882.....	D	D	D	D	D	I	I	I	I	I	I	I	I	D
1883.....	D	D	D	D	D	I	I	I	I	D	I	I	I	I
1884.....	D	D	D	D	D	I	I	I	I	D	D	D	I	I
1885.....	D	D	D	D	D	I	I	I	I	I	I	D	D	I
1886.....	I	D	I	D	D	I	D	D	D	D	D	D	D	I
1887.....	I	I	D	I	I	I	D	I	I	D	D	D	D	I
1888.....	I	I	I	I	I	I	I	D	D	D	D	D	D	I
1889.....	I	D	I	I	D	D	D	D	D	D	I	I	I	I
1890.....	I	I	D	D	I	I	I	I	D	D	D	I	D	I
D.....	7	8	8	6	6	2	6	5	7	10	8	6	8	4

M. T. SYSTEM.

1878.....	I	I	I	D	D	I	D	I	D	I	I	D	D	D
1879.....	D	I	D	I	D	I	I	D	D	D	I	D	D	D
1880.....	D	D	I	I	D	D	D	I	I	D	I	I	I	I
1881.....	I	I	I	I	D	D	D	I	D	I	I	I	D	D
1882.....	I	D	I	I	I	I	D	I	D	D	I	I	I	I
1883.....	I	I	I	D	I	I	I	I	I	D	I	I	I	I
1884.....	D	D	D	D	D	I	I	I	I	I	I	I	D	I
1885.....	D	D	D	D	I	I	D	D	I	D	D	I	I	I
1886.....	I	D	I	D	I	I	I	I	D	D	D	D	I	I
1887.....	D	I	D	I	I	I	D	D	I	D	I	D	D	I
1888.....	D	D	I	I	I	I	D	D	I	I	D	D	D	I
1889.....	I	D	I	I	I	I	D	D	D	D	D	I	I	I
1890.....	I	I	I	I	I	D	I	I	D	D	I	D	I	I
D.....	6	7	4	7	4	3	7	3	8	9	7	7	4	6

M. P. T. SYSTEM.

1878.....	I	I	I	D	I	I	I	D	D	D	D	I	I	I
1879.....	I	I	D	D	I	I	I	D	D	D	I	I	I	D
1880.....	D	I	D	I	I	D	I	I	D	D	I	D	I	I
1881.....	I	D	D	D	D	D	D	I	I	I	I	I	I	I
1882.....	D	D	D	D	I	I	I	I	D	D	D	I	I	D
1883.....	D	D	D	I	I	I	I	D	D	D	D	I	I	I
1884.....	D	D	D	D	D	I	I	I	I	I	I	I	D	I
1885.....	D	D	D	D	D	I	I	I	I	I	I	D	I	I
1886.....	D	D	I	D	I	I	I	I	D	D	D	D	D	I
1887.....	I	I	I	I	I	I	D	D	D	I	I	D	D	I
1888.....	D	D	I	I	I	I	D	D	I	D	D	D	D	I
1889.....	I	D	D	D	I	D	D	D	D	D	D	I	I	I
1890.....	I	D	I	I	I	I	I	I	D	D	D	I	D	I
1891.....	I	I	D	I	D	I	I	I	D	I	I	I	I	D
1892.....	I	D	D	D	I	I	I	I	D	D	I	I	I	I
1893.....	D	D	D	I	I	D	D	D	I	I	I	I	D	I
D.....	8	12	10	8	4	4	7	8	9	10	8	6	5	4

TABLE 21.—*Direct and inverse types, found by trials—Continued.*

M. SYSTEM.

Periods.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1841.....	I	D	D	D	D	I	I	D	D	D	D	D	I	I
1842.....	I	D	D	D	I	I	I	D	D	D	D	D	I	I
1843.....	I	I	I	D	I	I	I	D	D	D	D	D	I	I
1844.....	I	I	I	I	D	I	I	D	I	D	D	D	I	I
1845.....	D	D	D	D	I	I	I	I	D	D	D	D	I	I
1846.....	I	I	D	D	D	D	I	I	D	D	D	D	I	I
1847.....	I	D	D	D	I	I	I	I	D	D	D	D	I	I
1848.....	I	I	D	I	D	I	I	D	D	D	D	D	I	I
1849.....	I	I	D	I	D	I	I	D	D	D	D	D	I	I
1850.....	I	D	D	I	I	I	I	D	D	D	D	D	I	I
1851.....	I	D	D	D	D	I	I	D	D	D	D	D	I	I
1852.....	I	I	D	D	I	I	I	I	D	D	D	D	I	I
1853.....	D	D	D	D	I	D	I	I	D	D	D	D	I	I
1854.....	D	D	D	D	I	I	D	I	D	I	I	I	I	I
1855.....	D	D	D	D	I	I	I	D	D	D	D	D	I	I
1856.....	I	I	D	D	I	I	D	D	D	D	D	D	I	D
1857.....	I	I	D	D	D	I	I	I	D	D	D	D	D	I
1858.....	I	I	I	D	D	I	I	I	D	D	I	D	D	I
1859.....	I	I	I	D	D	I	I	I	D	D	D	D	I	I
1860.....	I	D	D	D	D	I	I	D	D	D	D	D	I	I
1861.....	D	D	D	D	D	I	I	D	D	D	D	D	I	D
1862.....	I	D	D	D	I	I	I	D	D	D	D	D	I	I
1863.....	I	I	I	D	D	D	I	I	D	D	D	D	I	I
1864.....	I	I	D	D	I	I	I	D	D	D	D	D	I	I
1865.....	I	I	D	D	D	I	I	I	D	D	D	D	I	I
1866.....	I	I	D	D	D	I	I	I	D	D	D	D	I	I
1867.....	I	D	D	D	D	I	I	I	D	D	D	D	D	I
1868.....	I	I	D	D	D	D	I	I	D	D	D	D	I	I
1869.....	D	D	D	D	D	I	I	D	D	D	D	D	I	D
1870.....	I	I	I	D	D	I	I	D	D	D	D	D	I	I
1871.....	I	I	D	D	D	I	I	D	D	D	D	D	I	I
1872.....	D	D	D	D	D	I	I	D	D	D	D	D	I	I
1873.....	D	D	D	I	I	I	D	D	D	D	D	D	I	I
1874.....	I	D	D	I	I	I	D	D	D	D	D	D	I	I
1875.....	D	D	D	I	D	I	I	D	D	D	D	D	I	I
1876.....	I	D	D	D	D	I	I	D	D	D	D	D	I	I
1877.....	I	D	D	D	D	I	I	D	D	D	D	D	I	I
1878.....	I	I	I	D	D	I	I	D	D	D	D	D	I	D
1879.....	I	I	D	D	D	I	D	D	D	D	D	D	I	D
1880.....	D	D	D	I	D	I	I	D	D	D	D	D	I	I
1881.....	I	D	D	D	D	D	D	D	D	D	D	D	I	I
1882.....	D	D	D	D	I	I	I	D	D	D	D	D	I	D
1883.....	D	D	D	D	I	I	D	D	D	D	D	D	I	I
1884.....	D	D	D	D	D	I	I	I	D	D	D	D	I	I
1885.....	D	D	D	D	D	I	I	I	D	D	D	D	I	I
1886.....	D	D	D	D	D	I	I	I	D	D	D	D	I	I
1887.....	I	I	I	I	I	D	D	D	D	D	D	D	I	I
1888.....	D	D	D	I	I	I	D	D	D	D	D	D	I	I
1889.....	I	D	D	D	D	I	D	D	D	D	D	D	I	I
1890.....	I	D	D	I	I	I	I	D	D	D	D	D	I	I
1891.....	I	I	D	D	I	D	I	D	D	D	D	D	I	D
1892.....	I	D	D	D	I	I	I	D	D	D	D	D	I	I
1893.....	D	D	D	I	I	D	D	D	D	D	D	D	I	I
1894.....	I	I	D	D	D	I	I	D	D	D	D	D	I	D
D.....	17	32	42	41	18	7	13	33	43	41	30	16	10	12
25.....	-8	+7	+17	+16	-7	-18	-12	+8	+18	+16	+5	-9	-15	-13

GENERAL LAW.

I	D	D	D	I	I	I	D	D	D	D	I	I	I
	Max.			Min.			Max.				Min.		

In an entirely similar manner the comparison has been made throughout this portion of the work, whose result is tabulated under the several systems now being described. Likewise, for the years 1878–1890, inclusive, the temperature curves were constructed for the Dakotas giving the T system; for 1878–1890 these same temperature curves, together with the European magnetic curve, were plotted in juxtaposition and taken as a pair in each period, producing the M T system;

for 1878-1893 the European magnetic curve, and the pressures and temperatures of the northwest, were also plotted in groups of three for each period, placed directly together so that the data of the same date fell on one vertical line, counting the Dakota data as one day elapsed, and they gave the system M. P. T.; finally, for 1841-1877, the magnetic curves from several parts of the world were collected in periods, the stations being placed to show synchronous action (Charts 17 and 18); for 1878-1894 the M. P. T. system was repeated in the M. table. It may be remarked in passing that these mean daily values of magnetic force indicate no eastward drift in longitude, such as B. Stewart supposed to exist in "magnetic weather," because these values are means for twenty-four hours. Such a superposition of material, gathered from all portions of the earth, if it should display any sympathetic and harmonious variations, indicates evidently some cosmical origin, and excludes as the primary causes any form of merely local changes. Having such general simultaneous disturbances, if any one attributes them to electrical or meteorological currents, then these must be shown to have a source capable of sustaining the observed effects. Variation of strength of an external magnetic field, in which the earth is immersed, will produce general disturbances of the entire terrestrial magnetic system, but that such states of the atmosphere as are known to meteorologists should by a counter process affect at once the entire system of atmospheric circulation in both hemispheres is not at all probable. It must be remembered that we are now dealing exclusively with mean values of twenty-four hours, and that diurnal changes are outside of our consideration. Hence if the electro-magnetic field does not change in intensity from day to day, appreciable variations in solar insolation having never been observed, or if the meteorological system taken as a whole is not self-active, that is, is not a primary source of energy, the only alternative in the argument is the variability of the polar magnetic field of the sun. We have shown that this is variable not only from meridian to meridian on the sun, but also that aperiodic impulses traverse the cosmical magnetic field in small and large disturbances, and it may be with minute wave-like pulsations superposed upon the normal field of force. Ebert sums up the well-known facts derived from the terrestrial observations as follows (Mag. Kraft, p. 52):

The movement of the lines has furthermore a yearly period, which expresses itself in this way, that the declination needle in both hemispheres points more easterly by some fractions of a minute of arc when the sun is north of the equator, that is, in our summer, and again more westerly when the sun is in the southern hemisphere during our winter. Likewise the inclination needle in both hemispheres shows an increase in the inclination in the season December, January, and a decrease of the same during July, August. In our winter, October to March, the intensity is greater in all parts of the earth than in the remainder of the year.

These changes are easily explained by the fact that in the approach of the earth to the sun in our winter it must pass into stronger parts of the magnetic field of the sun, and thus cause an increase of intensity of the

earth's force and an increase of inclination simultaneously all over the earth, on the principles already described.

There is one important argument to guard against. It may be said that the meteorological temperature changes precede and affect proportionally the observed strength of the magnetic field; but it will be conceded that the direct comparison of European magnetic data with the American meteorological system excludes this supposition, especially in view of the fact that no series of magnetic observations has ever been made in the northwest of the United States. Furthermore, magnetic observations are always conducted in rooms from which even the local temperature variations are practically excluded. On the other hand, this research has been greatly impeded by the total lack of a suitable series of magnetic observations in the Rocky Mountain districts; that is, one comprising several stations maintained continuously for a number of years. Toronto has a splendid series of observations, covering many years, which ought to be published; Washington has published a short series of three years; Los Angeles a ten-year series, but not for the same interval as Washington; San Antonio is not yet published. The Weather Bureau has enjoyed complete access to all these records, but they are not sufficient for the proper study of the problem now before us, chiefly because the observations are not simultaneous. An earnest hope is expressed that the United States may soon begin to make systematic observations, of equal value with those now going on under the European Governments. The available ground of comparison between the European magnetic and the American meteorological systems lies in the fact that the magnetic variations in Europe are proportional to the external field just outside the earth, which is impressed at the same time upon both hemispheres. The local peculiarities of any region, as the extreme northwest of the United States, can not, however, be carefully studied. This has constituted a barrier against the prosecution of this work to its completion, especially in its application to the problem of forecasting.

There are other remarks required concerning the comparison of the type curve with the individual periods to determine whether a given period is direct, D, or inverted, I. These two differ only in turning the same curve over on the long axis, the types being those given in Chapter I, Chart 9. (1) The distortions of successive periods are very great as compared with one another, arising from several interacting systems of forces. We are attempting to detect a delicate action, well-nigh buried among the other operations within the atmosphere. The work has been unusually difficult in many ways, especially in consequence of the fact that the periods can not always decisively be assigned to either type. (2) It was soon perceived that these irregularities are so great as to render it necessary to employ a large mass of material in order to extract a general law, and for this purpose fifty years of magnetic data are included. (3) It might be supposed that the grand sweep of the curve could be best depended upon to detect

the type, but on the whole it has been found that the sequence of the minor crests is more reliable, though both features are always considered together in an assignment of type. (4) This comparison of curves should always be done so as not to carry any preconceived impression of the probable type along from period to period, and therefore skipping about at random among the periods was the usual course followed. (5) An intercomparison of the four derived systems of types shows that about 70 per cent of the periods had a similar assignment, indicating that there is a decided probability in favor of a real inversion of the type curve. The systems herewith presented are merely the scaffolding of our investigation, and will be finally replaced by the general law of reversal which has emerged into view. It may be stated that I did not suspect what the law of the direct and inverse types was till I had finished the trial systems, and then discerned that the same law was to be found in each of them.

Referring to the D I Table 21, it is pointed out that each year was divided into the thirteen or fourteen periods given by the ephemeris; that a D or an I is inserted to indicate the probable conformity of the type curve to the curve derived from the observations in the direct or the inverse position during each period. Of course a transition may have occurred from one type to the other during a period, but the type covering the majority of days is entered. By using the four different systems of curves, extending over many years, an opportunity was presented for deriving contradictory results if the apparent conformity was really accidental; but the four results obtained having the same general conclusion, must be accepted as evidence that the observations lead to a single simple fundamental law. By carrying the work back over fifty years the ephemeris is sharply checked, because a small error in the period would throw the crests athwart the hollows of such a rapidly fluctuating curve within a few years; yet no sliding, even to the amount of one-tenth of a day, is believed to exist as far back as 1841. Every ten years of the system will give substantially the same law of relative frequency, which is a maximum of the D type during the 2, 3, 4 and the 8, 9, 10, 11 periods, and a maximum of the I type in the 5, 6, 7 and the 12, 13, 14, 1 periods. Near the middle of these groups the prevailing type is more firmly brought out than at the transition periods, where the neutral positions are occupied and a general uncertainty in the type to be assigned is likely to occur.

In Chart 19, with heading "Semiannual period of the direct type," the relations of the planes of the ecliptic, the sun's equator, the earth's equator, as projected in June on a plane perpendicular to the radius from the earth to the sun, is shown; also a curve of the relative frequency of the direct type. The frequency of the inverse type is found by turning this curve over on the long axis. The dates at the top of the diagram are the mean dates of the beginning of the ephemeris for the same period during the years 1841-1894, and therefore identify average points of occurrence on the D curve. The dates of transition

are such that the D type tends to prevail from about February 1 to April 20 and July 15 to October 15, while the inverse type holds for the intervals April 20 to July 15 and October 15 to February 1. The tendency to form these types vigorously increases according to the relative height of the ordinates, and passes through places of indifference when the curve crosses the ecliptic. There is a force, therefore, striving to order the succession of maxima and minima, as found in the normal solar magnetic curve, in this proportion. At certain seasons of the year this succession is completely inverted relatively to other seasons. Since this normal curve is shown to be common to the magnetic and meteorological phenomena, it follows that such a force can properly have its seat only in a body outside the earth.

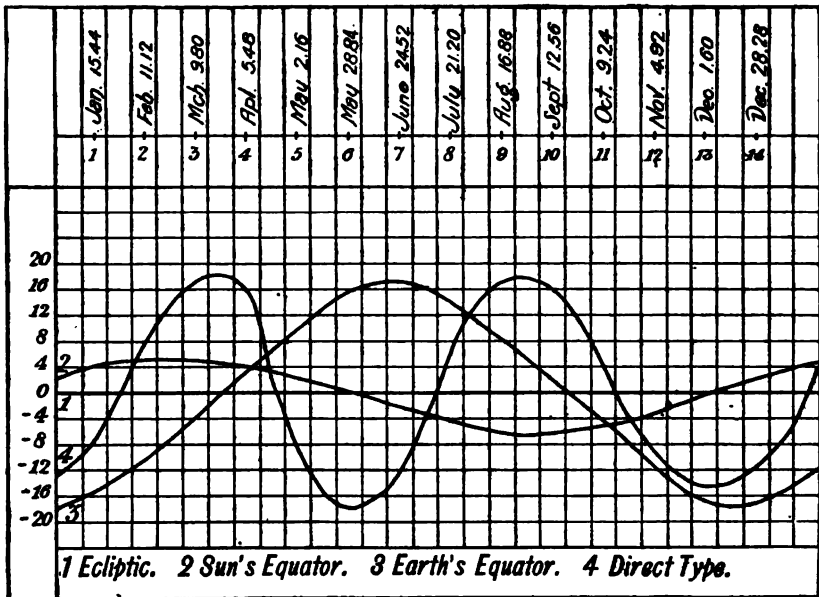


CHART 19.—Semiannual period of the direct type.

In order to see what relation this curve has to the astronomical triangle formed by the poles of the ecliptic K, sun's equator S, and earth's equator E, all four curves are projected on the plane of the ecliptic, with axis of the ecliptic passing through the center of the sun. Chart 20. It is perceived that the line of nodes perpendicular to K. S., is also the axis of the curve of the inverse type, and that K. S. is itself the axis of the curve of the direct type, the latter being omitted from the diagram. We conclude that such an outcome is not accidental, but has a cause in its relation to the axis of the sun, as defining the source producing the normal curve itself, and the phenomenon of inversion of the types. It would lead us too far from the immediate purpose of this chapter to give the solution of that point now, and it will therefore be reserved for another page. The analysis of a magnetic field, it may be

said in passing, emanating from a magnet placed with its axis on the average coincident with the axis of rotation of the sun, if its field by direct static action extends beyond the earth, should produce upon the earth's field exactly the phenomena described above. If this is so, then

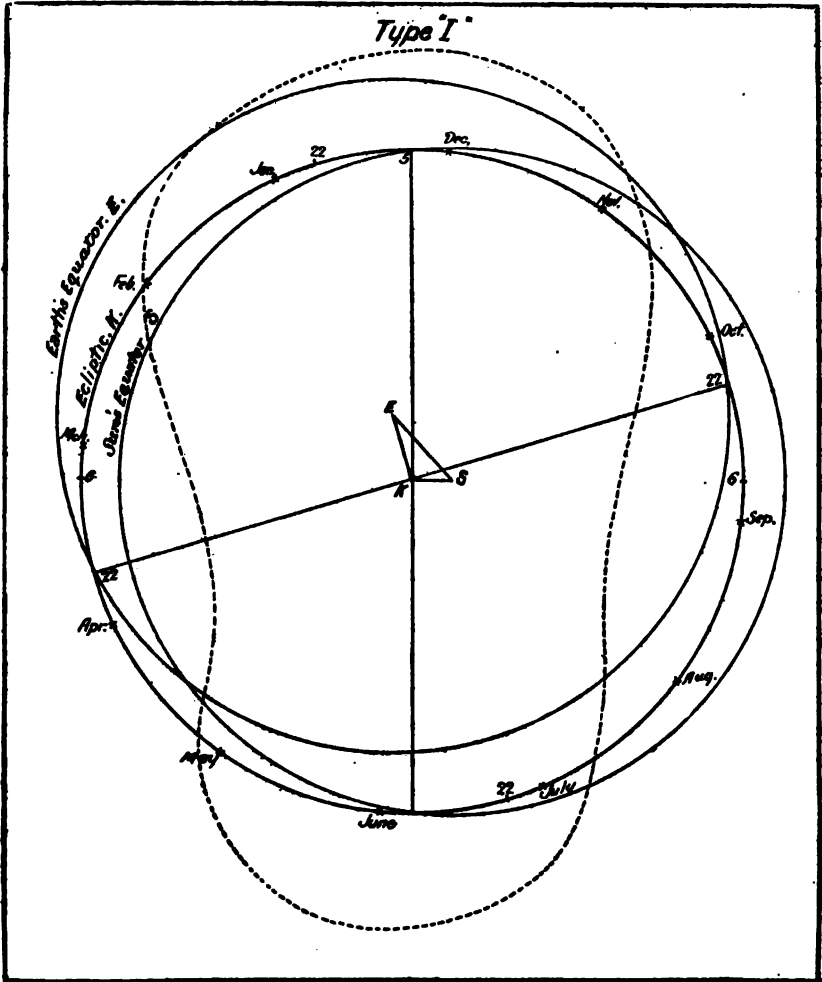


CHART 20.—Semiannual period of the inverse type, projected upon the ecliptic.

the theory of direct action of the sun as a magnet on the earth as a magnet will need no further defense. Whatever truth the theory of electric currents in the upper air may possess, whatever the final solution of the problem of radiation may be, the theory of direct action will merit respectful consideration among the premises.

SYNCHRONISM OF THE MAGNETIC AND THE METEOROLOGICAL
ELEMENTS IN THE 26.68 DAY PERIOD.

We will now return to the immediate subject of finding the normal curve of solar action and of discussing synchronous variations of the magnetic and meteorological systems with which we began this chapter. The subdivision of the periods into two groups is now simply performed. As an example, part of the tabulations of the M P T system are reproduced (Table 22, 23). All the D periods and all the I periods in 1878 and 1882, respectively, are added together, and the algebraic sums placed at the bottom of the tables. It may be remarked that this is numerically a wasteful process, so far as obtaining large surviving residuals is concerned, because of the very loose formations of individual periods relatively to any normal type. There seems to be no way to separate immediately the normal curve, and it can in a preliminary investigation be obtained only by survival in a long series of observations. Tables 20, 22, 23 are constructed in precisely the same way for the European magnetic force, the northwest pressures and temperatures. On Tables 24, 25, 26 the annual results are collected together for the years 1878-1893, keeping the D and I groups by themselves. The sums are then taken for the given interval. In case no periodic impulse is embedded in the observations, if the period is not correct, if inversion of type is not a fact, then in so long a series of variations, if they are purely accidental, the algebra sums should be about zero. But by comparing the final D and I sums it is seen that they tend to accumulate in large plus values on certain days of the period, and in large minus values on others; also that this tendency is opposite on the same days in the D and I groups. This is true of each of the three elements compared. The rapid succession of maxima and minima points on the resulting curve constitutes the chief difficulty in detecting it in every individual period, especially considering the relatively feeble action of the sun's magnetic field upon the convectional movements of the atmosphere.

TABLE 22.—Variations of the northwest pressures for 1878 and 1882.

[Units second decimal, inches.]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1878.													
Jan. 8.50	-34	+4	-32	-6	+33	+13	+8	-7	-15	-12	-8	-5	+6
Feb. 4.18	-43	-39	-15	-7	+7	+19	-9	-13	-4	-16	+3	0	+17
Mar. 2.86	+12	-1	-35	-23	-13	-53	-41	-33	-33	-1	-8	+20	-1
Apr. 29.54	+14	+85	+44	+27	+29	+14	+12	+8	-4	-39	-51	-7	-30
May 25.22	+4	+8	+5	-13	-16	-12	-34	-8	-6	-24	-42	-12	+2
June 21.90	-9	-39	-11	+1	+2	+5	+9	+4	+5	-2	-2	-16	+2
July 17.58	-10	-7	+5	+9	+1	+11	-2	-2	+8	+1	-10	-23	+3
Aug. 9.94	-21	-11	-3	-10	+6	+15	+26	+22	+14	+3	-17	-6	+13
Sept. 5.62	+6	+15	+1	-8	-15	+12	+15	-9	-5	+1	-12	-13	-18
Oct. 2.30	+5	+3	-11	+7	+33	+47	+25	+3	+2	+2	+5	+2	-2
Nov. 24.66	+19	+23	+23	-16	+2	-15	+14	-39	+8	-12	-27	-26	-37
Dec. 21.34	+17	+18	-17	-20	+10	+20	-2	-24	-43	-7	+1	+11	-8
Mean	16	16	19	13	13	19	16	15	12	12	16	13	15
D	+44	+76	+57	+10	+39	+58	+66	-37	+1	-48	-85	-44	-87
I	-111	-94	-33	-79	+48	+50	-23	-96	-96	-31	-28	+3	+56
1882.													
Jan. 14.90	-21	+31	+13	-1	-6	-20	+12	+44	+28	-9	-44	-15	-5
Feb. 10.58	-21	-32	+9	0	-11	+2	+37	-9	+30	-1	-1	+22	+20
Mar. 9.26	+36	+9	0	+6	-21	+15	+6	-41	-8	-3	-22	+16	+32
Apr. 4.94	-13	-24	-20	-27	-14	+8	-1	+20	+30	+33	+14	0	-7
May 1.62	-16	-10	-19	-16	-1	-16	-44	-35	-19	+2	+17	+19	+15
June 28.30	-1	-7	+9	+4	-11	+15	+21	+31	+22	-5	-8	-17	-9
July 23.98	-12	+1	+8	-1	-5	-19	-16	+1	+5	+4	+20	+1	-14
Aug. 20.66	+20	+12	+4	-7	-17	-1	-1	-3	0	-3	-8	0	+4
Sept. 16.34	+3	-7	+4	-4	-9	-3	-9	-10	-18	-15	-19	-19	+15
Oct. 12.02	+11	+3	-6	-21	-21	-20	+9	+28	+21	+21	+16	+3	+5
Nov. 4.38	+2	+14	-40	-47	-15	-26	-32	3	0	+20	+15	+17	-2
Dec. 1.06	+16	-12	-11	+11	-7	-39	-21	+6	+5	+6	-16	+11	+27
Mean	+43	-3	-11	-3	+16	+51	+8	-32	-2	-21	-21	-11	+13
D	+18	+1	+22	+30	+17	-6	+14	-3	+3	-29	-8	+27	-19
I	+5	-43	-40	-47	-39	0	-54	-12	+41	+16	-2	+3	+29

TABLE 23.—Variations of the northwest temperatures for 1878 and 1882.

[Units of Fahrenheit degrees.]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1878.													
Jan. 8.50	-1	+5	-1	+3	-1	-6	-6	-2	0	+1	+4	+3	+2
Feb. 4.18	+5	+8	+7	+3	-4	-9	-8	+2	-5	-2	-1	-3	-6
Mar. 2.86	-2	+3	+4	+5	+3	+8	+5	+2	+2	-4	-2	-3	+3
Apr. 29.54	-5	-4	-3	+1	0	+2	+2	1	+4	+4	+1	-5	-6
May 25.22	+3	+4	+8	+10	+8	+4	+5	-2	-8	0	+5	+7	+3
June 21.90	-1	+1	+3	+2	0	-3	-1	-1	-4	-2	+2	+2	0
July 17.58	+3	+4	+1	+1	+1	+4	+3	+4	-5	-1	+6	+5	-2
Aug. 9.94	+7	+10	+3	+3	+5	+4	0	-1	-2	-2	0	0	-5
Sept. 5.62	-4	-2	2	-1	-2	-4	-7	-6	-2	0	+1	+2	+6
Oct. 2.30	+2	+1	+6	0	-6	-12	-7	-7	0	+1	0	-1	+2
Nov. 24.66	-8	0	+1	+1	+4	-1	-5	-1	+2	+5	+3	+12	+5
Dec. 21.32	-8	-6	-12	-3	+1	-5	-1	+2	+8	-0	-4	-1	+5
Mean	-4	-9	2	+1	+1	0	+1	+5	+12	+10	+7	+2	-2
D	-7	-7	-13	-10	-1	-2	-3	-1	-1	0	-3	-20	-24
I	4	5	5	3	3	5	4	3	4	2	3	5	5
D	-4	-5	2	+1	-4	-15	-22	-15	+4	+10	+5	+9	+7
I	-5	+13	+2	+15	+12	-5	-5	+8	-8	0	+14	-8	-27
1882.													
Jan. 14.90	-7	-17	+3	-6	0	+5	-12	-21	-20	+1	+3	-14	-16
Feb. 10.58	+13	+7	+5	+18	+9	-24	-22	-18	-26	-9	-18	-16	-9
Mar. 9.26	-11	-4	-4	+4	+9	+7	+6	+10	-9	-7	-9	-16	-4
Apr. 4.94	+1	+2	+1	+3	-1	-3	-2	-3	-4	-1	+5	+5	+4
May 1.62	+4	+11	+8	+1	+2	+4	+1	+3	-1	-4	0	+2	+4
June 28.30	+5	+2	+1	0	-4	-6	-2	+4	+8	+8	+6	+1	-1
July 23.98	-8	-8	-6	-4	+1	+2	+1	+1	+3	0	+2	+3	+3
Aug. 20.66	0	-2	+5	+6	+5	+2	+2	-5	+1	+3	+1	+1	+4
Sept. 16.34	+1	+2	-2	+1	0	+4	+4	+4	+6	0	+10	-4	-7
Oct. 12.02	0	+5	+13	+6	-1	-6	-11	-9	-7	-7	-2	+6	+10
Nov. 4.38	-9	-6	-2	0	+5	+2	-4	-3	-6	-3	+4	+4	+3
Dec. 1.06	+7	+8	+3	+1	-3	-3	-11	-16	-7	+5	+7	+1	+5
Mean	0	+11	+5	-15	-24	-10	0	+2	-2	+1	-5	-16	-31
D	+6	+6	-3	-3	-6	-8	-21	-12	-6	-11	-6	+4	+32
I	5	6	4	5	5	7	8	8	8	4	6	7	9
D	-7	-7	+10	+20	+16	-20	-60	-49	-68	-36	-18	-96	+9
I	+9	+24	+17	-8	-24	-23	-11	-14	-2	+12	+16	-8	-2

TABLE 22.—Variations of the northwest pressures for 1878 and 1882.

[Units second decimal, inches.]

14	15	16	17	18	19	20	21	22	23	24	25	26	27	M. P. T.
+ 26	+ 2	- 25	+ 10	- 9	- 1	- 6	+ 2	+ 13	- 8	+ 9	+ 43	+ 23	- 9	I
+ 13	- 43	- 32	- 15	+ 6	+ 26	+ 19	+ 42	+ 85	- 10	- 9	- 16	- 17	.....	I
+ 30	+ 41	+ 14	+ 28	+ 19	+ 20	+ 18	+ 5	+ 81	- 2	- 40	- 7	+ 7	+ 24	I
- 6	+ 16	+ 13	+ 5	+ 12	- 39	- 10	+ 6	+ 6	+ 21	- 20	- 11	- 5	+ 17	D
+ 29	+ 34	+ 85	+ 38	+ 25	+ 13	- 8	- 2	+ 1	- 21	- 35	+ 2	+ 21	.....	I
+ 21	+ 21	+ 12	+ 2	- 32	- 12	+ 8	+ 1	+ 4	+ 14	+ 7	+ 5	+ 3	0	I
+ 18	+ 15	+ 4	+ 10	+ 3	- 5	- 5	- 4	- 5	+ 4	- 10	- 5	+ 8	+ 8	I
+ 6	- 4	- 12	- 6	- 2	- 2	- 3	- 3	- 4	- 1	+ 3	0	- 2	.....	I
- 5	+ 7	+ 24	- 14	- 6	+ 12	+ 17	- 4	- 7	+ 4	+ 10	+ 2	- 11	+ 1	D
- 20	- 2	+ 15	- 23	0	+ 5	+ 11	+ 51	+ 16	- 22	- 36	- 55	- 42	- 16	D
- 34	+ 7	+ 17	- 8	- 62	- 10	+ 8	- 3	+ 19	+ 35	+ 65	+ 48	- 3	.....	D
- 7	- 11	+ 14	+ 16	- 8	- 8	+ 8	- 19	- 7	- 34	- 5	- 9	- 46	- 5	I
- 30	- 17	- 40	- 10	+ 81	+ 47	- 18	- 6	+ 2	+ 25	+ 36	+ 33	- 2	- 7	I
+ 43	+ 44	- 23	- 27	+ 8	- 18	- 16	- 18	- 27	+ 14	+ 13	- 2	- 18	- 33	I
21	19	20	15	15	13	13	12	13	15	21	17	16	12	15.4
- 65	+ 28	+ 69	- 40	- 63	+ 19	- 3	+ 34	- 4	+ 19	- 16	- 61	+ 2	.....	.....
+ 149	+ 82	- 53	+ 44	+ 41	+ 65	+ 88	+ 3	+ 43	- 43	- 31	+ 44	- 3	- 22	.....
+ 24	+ 36	- 9	- 32	- 5	+ 2	+ 5	- 4	- 5	- 26	+ 20	+ 5	+ 2	- 9	D
+ 17	+ 3	- 3	- 34	- 34	- 32	1	+ 14	- 40	- 7	+ 22	+ 45	+ 16	- 8	D
+ 27	+ 86	- 25	- 34	- 6	- 34	- 18	- 36	+ 11	- 16	- 5	- 23	+ 1	.....	D
- 27	- 12	- 24	- 27	- 18	- 2	- 1	0	0	+ 10	+ 20	+ 42	+ 22	+ 14	D
+ 10	+ 19	+ 10	+ 3	- 23	+ 4	+ 21	+ 15	+ 23	+ 9	- 2	11	0	+ 7	I
+ 9	0	- 13	- 6	- 10	- 3	- 33	- 22	+ 4	- 13	+ 2	7	+ 6	.....	I
- 11	- 17	- 4	- 10	- 1	+ 13	+ 22	+ 2	- 17	+ 5	+ 4	+ 12	+ 9	+ 21	I
+ 7	0	- 2	+ 6	+ 13	+ 10	+ 15	+ 14	- 5	- 19	- 26	- 22	- 8	+ 6	I
+ 13	+ 18	+ 13	- 6	+ 7	+ 18	+ 12	+ 11	- 2	+ 4	+ 7	+ 4	- 8	- 15	D
+ 11	- 23	- 24	- 6	+ 9	+ 15	+ 8	+ 9	- 1	- 2	- 3	- 20	.....	.....	D
+ 12	+ 9	- 6	- 2	+ 9	+ 7	- 3	- 12	- 43	- 18	+ 32	+ 51	+ 40	0	D
+ 19	+ 7	- 8	+ 2	- 22	+ 7	+ 10	- 2	+ 8	+ 6	+ 7	+ 23	+ 12	- 3	D
+ 45	+ 10	- 26	- 36	- 39	- 22	- 12	- 4	- 19	+ 10	+ 11	+ 23	+ 37	.....	I
- 7	+ 8	- 61	- 5	- 5	- 2	- 8	- 8	- 1	+ 20	- 3	- 8	+ 26	.....	D
17	14	16	15	14	12	11	11	13	12	12	20	14	8	14.2
+ 97	+ 87	- 114	- 118	- 13	- 26	- 5	+ 43	- 71	- 44	+ 71	+ 71	+ 59	- 6	.....
+ 52	+ 7	- 67	- 68	- 90	+ 7	+ 33	- 3	- 6	+ 8	+ 25	+ 77	+ 78	+ 45	.....

TABLE 23.—Variations of the northwest temperatures for 1878 and 1882.

[Units of Fahrenheit degrees.]

14	15	16	17	18	19	20	21	22	23	24	25	26	27	M. P. T.
+ 3	- 8	+ 2	- 3	- 5	+ 2	- 6	- 6	- 2	- 1	- 2	- 1	- 3	- 2	I
- 8	+ 2	+ 3	+ 3	+ 1	+ 5	- 6	- 6	- 4	+ 3	+ 5	0	+ 2	.....	I
+ 2	- 2	+ 0	+ 5	+ 3	+ 3	+ 7	+ 7	+ 4	+ 6	+ 4	+ 6	+ 10	- 12	I
+ 1	- 2	- 6	- 5	+ 3	+ 6	+ 3	- 3	+ 2	+ 0	+ 3	+ 3	+ 1	+ 3	D
- 2	- 7	- 12	- 9	- 1	- 1	+ 1	- 1	- 1	- 3	- 3	- 2	- 4	.....	I
- 0	- 4	+ 0	0	0	0	+ 2	+ 0	+ 2	- 2	- 0	+ 4	+ 6	+ 9	I
- 4	- 4	- 3	- 3	- 3	+ 4	+ 3	+ 4	+ 4	+ 6	+ 4	+ 3	+ 3	.....	I
+ 5	+ 3	- 4	- 5	- 6	0	+ 3	+ 4	+ 6	+ 6	+ 3	+ 3	+ 7	+ 7	D
+ 7	- 3	- 7	- 6	- 6	0	0	+ 5	- 5	+ 3	+ 8	+ 9	+ 11	+ 5	D
+ 2	- 4	- 8	- 1	+ 6	+ 8	- 8	- 2	- 4	- 7	- 12	- 19	- 14	.....	D
0	+ 2	+ 2	- 2	+ 1	+ 4	+ 3	+ 7	+ 9	+ 4	+ 5	+ 9	+ 8	+ 4	I
+ 3	+ 9	+ 5	+ 6	- 4	- 4	- 2	- 1	+ 3	- 9	- 14	- 9	- 7	+ 6	I
- 17	- 13	- 6	+ 12	+ 5	- 7	- 2	0	+ 8	+ 7	- 8	- 9	- 6	0	I
4	5	4	5	3	4	4	4	4	4	5	6	6	5	4.2
+ 15	- 6	- 25	- 17	- 1	+ 11	+ 2	+ 14	- 1	+ 8	+ 2	- 4	+ 5	+ 15	.....
- 29	- 25	- 2	+ 7	- 7	- 8	- 6	+ 4	+ 24	- 4	- 10	0	- 17	+ 6	.....
- 23	- 5	+ 3	+ 4	+ 7	+ 6	+ 13	+ 12	+ 18	+ 11	+ 3	+ 2	+ 10	+ 17	D
+ 1	+ 7	+ 5	+ 20	+ 20	+ 17	+ 13	+ 12	+ 9	- 12	- 23	- 18	- 8	- 6	D
- 14	- 8	+ 3	0	- 4	+ 11	- 11	- 7	+ 12	+ 12	+ 15	+ 6	+ 7	.....	D
+ 2	0	+ 4	- 2	- 2	+ 1	+ 1	0	- 2	1	- 1	- 4	- 2	- 6	I
+ 6	+ 9	+ 5	+ 3	- 3	- 13	- 17	- 17	- 8	- 1	+ 1	- 1	- 2	+ 3	I
0	+ 4	+ 1	- 1	- 4	- 9	- 13	- 14	- 10	- 7	- 7	- 6	- 5	- 4	I
+ 4	+ 4	+ 1	- 3	- 9	- 7	- 7	- 3	- 5	- 5	- 4	- 6	- 5	- 4	I
+ 6	+ 7	+ 7	+ 7	+ 1	- 2	- 4	0	0	- 3	0	- 2	- 1	0	D
- 8	- 10	- 7	- 4	+ 1	+ 2	- 2	0	+ 2	- 1	+ 1	+ 2	+ 2	+ 1	D
+ 10	+ 4	- 1	- 7	- 7	0	+ 6	+ 6	+ 8	+ 5	+ 1	- 1	- 5	.....	D
+ 2	+ 5	+ 7	- 1	+ 5	- 6	- 1	- 2	+ 1	- 5	- 4	- 4	+ 1	+ 6	D
+ 8	+ 9	+ 9	+ 7	+ 2	- 5	- 7	- 3	- 4	- 1	- 3	0	+ 9	+ 3	I
- 10	+ 9	+ 14	+ 15	+ 12	+ 6	+ 1	+ 4	+ 6	+ 6	+ 9	+ 5	+ 4	.....	I
+ 11	+ 11	- 2	- 2	- 2	+ 7	+ 13	- 9	- 14	- 20	- 18	- 13	- 12	- 4	D
8	7	6	5	5	6	7	6	7	7	7	5	5	4	6.2
- 21	+ 4	+ 21	+ 10	+ 12	+ 49	+ 30	+ 12	+ 36	- 7	- 21	- 26	- 14	+ 14	.....
+ 16	+ 42	+ 41	+ 28	0	- 24	- 42	- 32	- 27	- 13	- 5	- 15	- 3	- 4	.....

TABLE 24.—*Summary of horizontal component ϕ . (System M. P. T.)*

DIRECT TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	- 218	-125	-207	-117	+ 51	- 221	+ 60	+ 70	+ 155	+ 80	+213	+ 272	+ 151
1879...	+ 176	+ 5	+194	+183	+ 235	+ 329	- 83	-235	- 88	+ 324	+126	+ 115	- 86
1880...	+ 256	+315	+237	+347	+ 171	+ 403	+228	- 30	+ 92	+ 223	+201	+ 238	+293
1881...	- 344	+ 8	+ 37	-243	- 28	- 210	-185	-105	- 77	+ 74	+244	+ 248	+ 647
1882...	- 213	-316	+ 70	+445	+ 358	+ 130	- 68	- 37	+ 329	+ 594	- 52	- 31	+ 76
1883...	+ 152	+506	+ 74	-246	- 51	- 114	+108	+239	+ 287	+ 337	-451	- 406	+ 117
1884...	+ 360	+265	+201	-140	- 664	- 571	-361	-367	- 127	+158	+ 85	+ 131	+286
1885...	+ 375	+295	+195	+281	+ 459	+ 412	-529	-361	- 632	- 431	-762	- 491	+192
1886...	+ 193	-527	+609	-485	- 55	+ 385	+331	+298	+ 281	+ 561	+750	+ 706	+ 573
1887...	- 105	-400	-423	-470	- 430	- 95	+ 69	+172	+ 46	- 31	- 87	+ 160	+ 5
1888...	+ 648	+326	-192	+ 1	- 236	+ 12	- 98	-161	- 145	- 180	+ 31	+ 134	- 104
1889...	+ 96	-123	-146	+ 14	+ 208	+ 130	- 49	- 52	+ 157	+ 198	- 53	+ 207	+ 357
1890...	+ 188	+ 61	+298	+291	+ 349	+ 175	+240	+275	+ 142	+ 23	+ 93	+ 199	+ 184
1891...	- 170	+ 84	- 54	-230	+ 252	+ 336	- 6	+230	+ 325	+ 191	- 11	+ 66	+ 42
1892...	- 412	-240	-210	-236	- 50	+ 180	+360	+178	+ 136	+ 376	+428	+ 500	+ 449
1893...	+ 25	+214	+610	+340	+ 561	+ 421	+458	+308	+ 291	+ 308	+158	+ 363	- 67
D...	+1007	+348	+ 75	-265	+1132	+1698	+475	+422	+1172	+2499	+913	+2411	+3115

INVERSE TYPE.

1878...	+ 214	+ 468	+ 545	+ 22	- 131	- 248	+168	- 304	- 202	+ 118	+ 90	+ 99	+ 411
1879...	+ 183	+255	+123	+ 32	+109	- 116	-352	- 226	- 247	- 26	-165	- 245	- 89
1880...	+ 172	- 53	+171	- 90	+ 83	+ 98	+178	+ 142	- 130	+ 219	- 75	- 59	+ 25
1881...	+ 474	+ 1	+127	+ 611	+ 511	- 246	+234	- 285	- 180	- 416	- 518	+ 39	+ 117
1882...	+ 180	+164	+ 450	+ 474	+ 415	+ 274	+387	+ 571	+ 561	+ 690	+ 539	+ 427	+ 397
1883...	+ 52	+259	+345	+379	+ 304	+ 253	+129	+169	- 148	+ 1	-177	+ 81	- 147
1884...	+ 465	+274	+ 327	+ 453	- 116	- 166	-265	+ 853	+ 742	+ 223	- 575	- 314	+ 25
1885...	+ 626	+ 20	+135	+273	- 358	- 175	+ 99	+157	- 85	- 29	+ 37	- 36	+ 94
1886...	+ 337	-283	- 359	- 135	- 87	- 103	- 74	+135	+ 219	+ 363	+ 64	+ 215	+ 383
1887...	- 166	-280	- 278	- 31	- 79	+ 71	+ 65	+392	+ 524	+ 413	+ 290	- 145	- 421
1888...	+ 160	+ 36	+348	- 136	- 357	- 277	-192	+ 269	+ 418	+ 274	+ 186	- 628	- 660
1889...	+ 155	+ 44	- 30	- 54	+114	+ 97	+121	+ 214	+ 95	- 70	- 92	+ 143	+ 165
1890...	- 2	+280	+242	+159	+217	+ 270	-130	+100	+118	+ 146	+ 326	+ 285	+ 57
1891...	+ 182	+148	- 595	- 144	- 156	- 34	+ 16	- 38	+330	- 384	- 699	- 236	- 67
1892...	- 346	- 341	- 341	- 26	- 589	- 349	+121	+ 497	- 75	+ 170	+ 380	+ 44	- 19
1893...	+ 216	+ 323	+ 295	+ 484	0	+ 144	- 87	+ 10	- 14	+ 68	- 229	- 125	- 290
I....	+2902	+1315	+1505	+2271	- 118	- 507	+418	+2176	+1926	+1760	- 628	- 495	- 19
D-I....	-1895	- 987	-1430	-2536	+1250	+2207	+ 57	-1754	- 754	+ 739	+1541	+2906	+3134

TABLE 25.—*Summary northwest pressure variations. (System M. P. T.)*

DIRECT TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	+ 44	+ 76	+ 57	+ 10	+ 39	+ 58	+ 66	- 37	+ 1	- 48	- 85	- 44	- 87
1879...	- 6	- 54	-115	+ 4	- 39	+ 10	- 26	+ 69	+ 64	- 20	- 36	- 68	+ 19
1880...	- 94	- 23	+ 15	- 17	- 34	+ 21	+ 62	+ 74	+ 64	+ 1	- 26	- 23	+ 15
1881...	- 9	- 5	- 30	+ 16	+ 41	+ 13	+ 7	+ 3	+ 24	- 9	- 34	+ 10	+ 18
1882...	+ 0	+ 19	+ 2	- 37	- 66	- 58	+ 37	+ 6	- 56	- 7	- 63	+ 51	+ 86
1883...	- 1	+ 82	- 43	- 10	+ 15	+ 3	- 16	+ 60	+ 64	+ 33	+ 27	+ 59	+ 19
1884...	+ 13	- 7	- 45	- 26	+ 48	- 49	- 26	- 11	+ 22	+ 36	+ 68	+ 8	- 14
1885...	+ 31	- 27	- 70	-107	+ 2	- 9	+ 27	- 13	- 10	+ 31	+ 11	+ 25	+ 45
1886...	+ 34	- 18	- 97	- 62	+ 47	+ 33	+ 41	- 16	+ 81	+ 14	- 41	- 1	- 20
1887...	+ 85	- 31	- 50	- 15	- 9	+ 32	+ 47	+ 19	+ 22	+ 6	- 5	+ 11	- 36
1888...	-118	- 30	- 1	+ 21	+ 1	- 44	+120	+ 86	+ 57	- 23	- 37	- 32	- 88
1889...	- 34	- 24	- 84	-122	- 42	- 86	- 59	+ 82	+154	+ 92	+ 37	+ 46	+ 15
1890...	+ 4	+ 13	- 21	+ 73	+ 32	- 23	- 55	+ 51	+ 15	- 1	+ 57	+ 56	- 50
1891...	- 3	0	+ 13	0	- 31	- 69	- 45	+ 15	- 16	+ 57	+ 24	- 47	- 39
1892...	+ 8	+ 30	+ 17	+ 69	+ 93	+ 50	- 27	- 17	- 22	+ 11	+ 38	+ 18	- 13
1893...	- 36	+ 7	- 27	- 8	- 4	- 25	- 24	+ 64	+ 70	+ 6	+ 23	+ 10	+ 11
1894...	- 20	- 42	- 69	+ 13	+ 10	+ 88	+ 65	+ 71	+ 78	+ 28	- 32	- 32	- 94
D...	- 56	- 34	-458	-198	+103	- 55	+294	+ 404	+ 756	+207	- 74	+ 47	-353

TABLE 24.—Summary of horizontal component σ . (System M. P. T.)

DIRECT TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
+ 145	+ 106	+ 225	+ 126	+ 150	— 98	— 131	— 3	— 1	+ 3	— 54	— 118	+ 23	— 32
+ 7	— 460	— 292	— 213	+ 338	+ 462	+ 150	+ 61	— 124	+ 156	— 121	— 316	+ 91	+ 148
+ 295	+ 287	+ 184	+ 109	— 6	— 39	— 4	— 12	— 88	— 165	— 12	+ 195	+ 63	+ 82
+ 164	+ 32	+ 338	+ 444	+ 296	— 171	— 254	— 31	+ 63	+ 219	+ 386	+ 99	— 54	+ 100
+ 273	+ 481	+ 396	+ 548	+ 366	+ 399	+ 424	+ 365	— 69	+ 172	+ 304	— 135	+ 106	+ 290
+ 204	+ 109	+ 287	+ 480	+ 14	— 30	+ 144	+ 163	+ 458	+ 50	+ 312	+ 105	— 189	— 83
+ 569	+ 345	+ 492	+ 575	+ 470	+ 209	+ 236	+ 538	+ 43	— 205	— 179	— 651	— 416	— 136
+ 152	— 71	+ 485	+ 558	+ 443	— 348	+ 412	+ 87	+ 383	+ 343	+ 97	+ 481	+ 365	— 58
+ 599	+ 315	+ 581	+ 356	+ 709	+ 298	— 520	— 889	— 761	— 468	— 278	— 6	— 55	+ 32
+ 79	+ 308	+ 206	+ 235	+ 60	— 60	+ 285	+ 68	+ 219	+ 334	+ 501	+ 350	+ 37	+ 48
— 90	— 106	— 25	+ 265	— 121	— 156	— 89	— 341	+ 85	+ 289	+ 240	+ 267	+ 444	— 524
+ 144	+ 274	+ 153	+ 171	+ 270	+ 205	+ 219	— 279	— 406	— 262	— 382	— 109	— 120	+ 134
— 41	— 398	— 155	— 203	— 42	— 290	— 243	+ 116	+ 30	— 20	— 72	— 4	+ 47	— 36
+ 157	— 40	+ 103	+ 5	+ 68	— 139	— 198	— 46	— 94	+ 304	+ 146	+ 10	+ 70	— 122
+ 558	+ 42	+ 330	+ 603	— 336	— 356	— 38	— 18	— 115	— 472	— 455	— 271	— 58	+ 188
— 177	— 383	+ 149	+ 142	+ 264	+ 154	+ 217	+ 142	— 25	— 428	— 323	— 268	+ 285	— 10
+ 3038	+ 818	+ 8457	+ 4201	+ 2943	+ 40	— 214	— 79	— 402	+ 180	— 414	— 281	+ 755	+ 773

INVERSE TYPE.

— 20	+ 83	— 7	— 31	+ 341	+ 546	— 1	— 38	— 74	+ 19	— 80	— 102	+ 59	+ 209
— 263	— 286	— 116	+ 171	+ 245	+ 463	+ 12	— 285	— 244	— 150	+ 129	+ 276	+ 154	+ 248
— 244	— 258	— 180	— 24	— 277	— 347	— 291	— 333	— 381	— 421	— 161	+ 65	+ 86	+ 540
+ 213	— 42	+ 241	— 312	— 358	— 433	+ 47	+ 497	+ 370	+ 530	+ 477	+ 317	+ 2	+ 1
— 464	— 322	— 672	— 829	— 713	— 1028	— 603	— 698	— 671	— 273	+ 302	— 125	+ 419	+ 448
+ 15	+ 246	+ 111	— 353	+ 833	+ 291	— 541	+ 150	— 19	+ 6	+ 99	+ 233	+ 371	+ 220
+ 13	+ 508	+ 667	— 364	— 744	— 438	+ 60	+ 53	— 131	+ 173	+ 324	+ 308	+ 266	+ 394
+ 330	+ 292	— 494	— 520	+ 23	+ 97	+ 98	+ 266	+ 66	+ 21	+ 208	+ 849	+ 42	+ 140
+ 894	+ 347	— 12	— 265	— 111	+ 75	+ 187	— 2	— 53	— 175	— 30	+ 170	+ 322	+ 265
— 141	— 211	— 385	— 25	— 58	+ 50	+ 324	+ 365	+ 640	+ 384	+ 595	— 217	— 585	— 127
— 410	— 228	— 243	+ 157	+ 263	+ 358	— 238	+ 102	+ 198	+ 221	+ 482	+ 48	+ 151	+ 27
+ 246	+ 383	+ 839	+ 302	+ 145	— 6	+ 15	— 374	— 152	— 449	— 228	— 303	+ 23	— 13
+ 211	+ 140	+ 162	+ 67	— 1	— 323	— 57	+ 37	— 183	+ 53	+ 257	+ 34	+ 339	+ 242
+ 128	+ 471	+ 382	— 48	+ 192	— 174	+ 8	+ 148	— 54	— 242	— 204	+ 55	+ 144	— 74
+ 712	+ 353	+ 172	+ 61	+ 230	+ 230	+ 490	+ 653	+ 329	+ 185	+ 388	+ 799	+ 790	— 51
— 413	— 498	— 475	— 231	+ 51	+ 128	+ 261	+ 481	+ 421	+ 471	+ 66	— 5	+ 48	+ 43
— 115	+ 983	— 510	— 2558	— 539	— 1083	+ 226	+ 1022	+ 63	+ 309	+ 2624	+ 1872	+ 2835	+ 2512
+ 3153	— 165	+ 3973	+ 6759	+ 3482	+ 1123	— 440	— 1101	— 464	— 123	— 3038	— 2153	— 2080	— 1789

TABLE 25.—Summary northwest pressure variations. (System M. P. T.)

DIRECT TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
— 65	+ 28	+ 69	— 40	— 63	+ 19	— 3	+ 34	+ 34	— 4	+ 19	— 16	— 61	+ 2
— 25	— 30	— 16	— 51	— 66	— 8	+ 52	+ 77	+ 17	+ 40	+ 63	— 26	— 44	— 68
— 15	+ 56	— 41	— 114	— 78	— 32	+ 67	+ 33	— 1	— 23	+ 50	+ 47	— 12	+ 13
+ 25	— 40	+ 5	— 15	— 28	— 7	+ 33	+ 15	— 20	— 77	— 26	+ 47	+ 54	— 12
+ 97	+ 87	— 114	— 118	— 13	— 26	— 5	+ 43	— 71	— 44	+ 71	+ 71	+ 59	— 6
— 27	+ 35	+ 78	— 4	— 112	— 124	— 40	— 21	— 84	— 78	+ 5	+ 62	+ 5	— 19
+ 3	+ 32	+ 7	— 37	— 41	+ 1	0	+ 4	+ 8	+ 4	+ 2	— 82	— 51	+ 7
— 13	— 12	— 10	+ 12	— 7	— 62	+ 73	+ 74	+ 31	— 19	+ 2	+ 14	+ 58	+ 16
+ 44	— 52	+ 91	— 51	— 43	— 16	— 46	+ 87	+ 4	— 13	— 30	— 72	+ 22	+ 30
— 27	+ 68	— 10	+ 15	— 12	— 18	— 31	+ 16	— 30	— 68	+ 18	+ 79	— 27	+ 16
— 52	+ 27	+ 50	+ 20	+ 15	+ 2	— 11	+ 94	+ 93	+ 59	+ 79	+ 57	— 37	— 73
— 58	+ 40	+ 31	+ 61	+ 20	— 15	— 2	+ 32	+ 50	+ 7	— 27	— 20	— 63	— 39
+ 13	— 28	— 22	+ 60	— 07	+ 8	+ 22	+ 13	— 38	— 18	+ 109	+ 55	— 5	— 24
+ 18	+ 26	— 40	+ 11	— 1	+ 1	+ 36	+ 55	+ 22	— 4	— 31	+ 13	+ 36	+ 41
— 48	+ 15	+ 18	+ 43	— 05	— 62	— 44	— 43	— 35	— 13	+ 19	+ 1	+ 40	+ 47
— 7	— 14	— 33	— 48	— 39	— 158	+ 18	+ 83	+ 13	— 54	+ 27	+ 6	+ 20	+ 69
— 91	— 60	— 41	— 87	+ 30	+ 46	+ 55	+ 3	— 20	+ 70	+ 81	— 39	+ 31	+ 39
— 274	+ 198	+ 22	— 571	— 621	+ 431	+ 174	+ 590	— 27	— 243	+ 437	+ 143	— 37	+ 39

TABLE 25.—Summary northwest pressure variations. (System M. P. T.)—Continued.

INVERSE TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	-111	-94	-33	-79	+48	+50	-23	-96	-96	-31	-28	+3	+56
1879...	-41	+78	+38	+21	+15	-25	-65	-96	-154	-71	+53	+22	+27
1880...	-16	-62	+1	+33	-22	-29	-108	-76	-25	+99	+7	+110	+108
1881...	0	-7	+7	+46	+21	-90	-31	-73	-63	+45	+10	+37	+38
1882...	+5	-43	-40	-47	-39	0	-54	-12	+41	+16	+2	+3	+29
1883...	-33	+99	+84	-10	+60	+23	-86	-194	-111	-39	-9	-9	-60
1884...	-65	-58	-33	-62	+45	+24	-15	+1	+25	-10	-13	+10	+10
1885...	+14	+43	+35	+39	-16	-51	-22	+1	+2	+13	-16	+7	+48
1886...	-67	-80	-64	-48	-19	+33	+31	+22	-42	+10	+28	+45	+8
1887...	+44	+26	+1	+16	+120	+150	+80	-123	-134	-25	-32	-95	+41
1888...	-25	+18	-8	-56	+52	+97	+71	+51	+41	+71	+82	+19	-61
1889...	-31	-126	-62	-48	+37	+45	+88	+47	0	-1	-44	-41	-4
1890...	-71	-66	+69	+43	+46	+105	+57	+12	+22	+36	+33	+14	-17
1891...	-3	+2	+178	+73	-17	-52	-104	-118	-99	-69	-15	+33	+6
1892...	+20	+46	+51	+32	-43	-22	+15	-98	-98	-34	+40	+46	+29
1893...	+77	+12	+41	+48	+44	-54	-65	-62	-21	+46	-57	-61	-1
1894...	-23	+23	-62	-35	-89	+15	+1	-20	-59	-25	+53	+57	-60
I...	-256	-149	+194	-104	+233	+171	-280	-828	-711	-29	-13	+71	+187
I-D...	-200	-115	+652	+94	+130	+226	-574	-1233	-1467	-236	+61	-24	+540

TABLE 26.—Summary northwest temperature variations. (System M. P. T.)

DIRECT TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	-4	-5	+2	+1	-4	-15	-22	-15	+4	+10	+5	+9	+7
1879...	-7	-3	-10	+18	+6	+3	-11	-9	-20	+7	+14	+8	+9
1880...	+36	+35	+17	+7	+8	-1	-23	-38	-21	-23	-1	-2	+9
1881...	+34	+34	+32	-9	-21	-5	-2	-4	-18	-16	-6	-11	-13
1882...	-7	+7	+10	+20	+16	-20	-60	-49	-68	-36	-18	-36	+9
1883...	-35	-9	+6	+9	-3	+22	+8	-16	-31	-29	-38	-21	-24
1884...	+7	-1	-14	+4	-22	+5	-6	-11	-39	-21	-12	+25	-2
1885...	-34	-5	-3	+7	-34	-33	-13	-26	-45	-23	-30	-25	-27
1886...	-13	+4	+33	+31	+10	+17	+25	+5	-22	-12	-14	-24	-28
1887...	-26	+14	-1	-1	-5	-3	-11	-34	-12	-16	-7	-6	+2
1888...	-29	-60	-34	-32	-15	-18	-40	-26	-18	+14	+27	+21	+36
1889...	+4	+3	+11	-1	-11	+5	+9	-9	-31	0	+12	+21	+16
1890...	+39	+29	+36	+16	+35	+31	+35	+30	+7	+31	+11	-5	-4
1891...	-6	-3	-23	-32	-20	-3	-26	-34	-21	-6	+15	+34	+9
1892...	-35	-25	-32	-30	-35	-25	-12	+3	+8	+7	+1	+12	+17
1893...	-28	-19	-22	-27	-5	-11	0	-22	-1	+9	+8	+7	+7
1894...	+32	+39	+33	0	-1	-5	-17	-2	+10	+24	+17	+15	+18
D...	-73	+31	+41	-19	-101	-56	-166	-257	-308	-80	-21	+22	+41

INVERSE TYPE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1878...	-5	+13	+2	+15	+13	-5	-5	+8	-3	0	+14	-8	-27
1879...	-13	-41	-7	-7	+9	+1	+12	+18	+19	+48	-7	+5	+18
1880...	-25	+13	+24	+7	+13	+11	+22	+32	+17	+23	+13	+9	+1
1881...	-8	-12	-22	+10	+26	+16	-21	+8	+1	+23	-1	-12	-3
1882...	+9	+24	+17	-8	-24	-23	-11	-14	-2	+12	+16	-8	-2
1883...	+5	-4	+8	+17	+19	+34	+13	+11	-12	-6	+15	+1	+8
1884...	-15	-83	-36	-19	-35	-34	-15	-14	-2	+2	+6	+3	+8
1885...	+27	+20	+29	+43	+28	-8	-27	-27	-15	-8	-11	-16	-46
1886...	+23	+17	+15	+25	+17	+22	+5	+12	+16	+14	-7	+6	0
1887...	-2	-12	-23	-50	-64	-38	-25	-41	+27	-10	+18	+14	-35
1888...	-17	-13	+10	-16	-34	-24	+7	+14	+34	+29	+52	+84	+36
1889...	+5	-1	+3	-19	+6	-17	-30	-15	-4	+14	+22	+14	+19
1890...	-6	-24	-44	-39	-42	-26	-7	+9	-8	-39	-17	-17	+79
1891...	-16	-49	-82	-11	+22	+11	+16	+55	+40	-1	-15	-31	+10
1892...	-5	+16	-17	+12	+22	-3	-18	+8	+49	+26	+21	+26	+4
1893...	-6	-12	-19	-15	-23	+9	+6	0	-21	-21	-5	-8	-21
1894...	-21	-14	+19	+24	+35	+13	-9	-3	+6	-8	-15	+7	+9
I...	-70	-112	-123	-3	-12	-61	-87	+143	+142	+103	+99	+29	+5
D-I...	-3	+143	+164	+12	-89	+5	-79	-400	-450	-183	-120	-7	+36

TABLE 25.—Summary northwest pressure variations. (System M. P. T.)—Continued.

INVERSE TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
+149	+82	-53	+44	+41	+65	+38	+3	+43	-43	-31	+44	-3	-22
+133	+38	-46	+88	+42	+20	-14	+37	+69	+44	-124	-76	-1	+1
+30	+51	-45	+35	+85	+87	+31	-25	-82	-20	-26	0	-38	+14
+15	+59	+19	+10	+6	+7	+25	-30	+13	-20	+14	+8	-4	0
+52	+7	-67	-68	-80	+7	+32	-3	-6	+8	+25	+77	+78	+45
-6	0	+33	-27	-42	-32	+87	-14	+9	+62	0	+29	+45	+80
+32	+51	+38	+63	+49	+7	-6	-52	-54	+40	+13	+55	-0	-44
+52	+17	-27	1	-13	-41	-13	+19	+9	-5	-67	-27	-5	+2
+31	+2	+10	+4	-10	+10	+15	+22	+8	-55	+13	+53	+57	-19
+84	-53	-99	-77	-129	-89	-18	-35	-11	-48	-13	+3	+38	-3
-22	-51	+89	+32	-15	-22	-30	+5	+1	-65	-122	-100	-67	+18
-13	-39	-27	+12	+2	+61	+74	+30	+11	+45	+81	-52	-81	+21
-52	-127	-87	+13	+68	+80	+5	-76	+22	-34	-80	-3	-17	+4
+11	+40	+45	+46	+14	+21	+16	-72	-59	+45	-34	-10	-16	+15
+2	+57	+136	+66	+62	+51	+1	-46	-14	-2	-34	-64	-73	+18
+25	-15	-62	-47	-82	+23	+1	-10	+27	+61	+20	+37	+48	+41
+7	+60	+132	+81	-1	+6	+134	-20	-35	-75	-2	-17	-26	+12
+536	+179	-16	+280	-3	+261	+378	-267	-49	+25	-367	-43	-71	+178
+810	-19	-38	+851	+618	+692	+204	-866	-22	+268	-804	-186	+34	+139

TABLE 26.—Summary northwest temperature variations. (System M. P. T.)

DIRECT TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
+15	-6	-25	-17	-1	+11	+2	+14	-1	+8	+2	-4	+5	+15
-6	+12	+30	+14	+44	+46	+31	-6	-15	-13	+20	-12	+9	-1
+22	+2	-4	+34	+30	-3	+25	-37	-41	-15	-22	-41	-16	+2
-32	-14	+1	+16	+10	+9	+13	+10	+35	+22	-12	-25	+20	+25
-21	+4	+21	+10	+12	+49	+30	+12	+36	7	-21	-26	-14	+14
-24	-38	+7	+26	+20	+22	+10	+30	+28	0	-20	+12	+24	+37
-7	-10	+15	+16	+1	+12	+6	2	+21	+23	+16	+20	+6	-18
-27	-9	+12	+7	+44	+57	+17	+33	+58	+36	+23	+15	-15	-14
+5	+21	+36	+55	+32	+6	-28	-59	-23	-23	21	-40	-21	-12
+11	-25	-16	+15	+9	+22	+9	+2	+6	+26	+17	+7	+7	-30
+17	+13	+22	+11	+23	+7	+4	+16	+4	+12	-28	-29	+1	-34
+13	+7	+6	+11	+14	+24	+10	+5	-23	-10	+14	+7	+20	-15
-35	-82	-22	-13	-13	-22	-44	-34	-12	-14	-20	-13	+18	-21
+14	-2	+23	+10	+17	-4	-13	-4	+12	+6	-3	-3	-13	-19
+6	+12	+16	+13	+9	+21	+15	+18	+21	+29	-3	+5	+20	-16
+6	+11	+10	+33	+26	+19	+13	+15	+7	-15	-33	-31	-37	-20
0	+6	0	+24	+13	+23	+10	0	-21	-44	-23	+8	+23	+9
-43	-84	+132	+235	+299	+299	+52	+17	+89	+15	-154	-149	+37	-56

INVERSE TYPE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27
-39	-25	-2	+7	-7	-8	-6	+4	+24	-4	-10	0	-17	+6
-28	-41	-9	-11	-17	+7	-8	-1	-27	-18	+22	+36	+7	+16
+15	+6	-2	-2	-26	-27	-4	+15	+22	+32	-6	-10	+2	-12
-8	+4	+11	+19	+22	-1	0	-10	-25	-20	-16	-24	+3	+14
+16	+42	+41	+28	0	-24	-42	-32	-27	-13	-5	-15	-3	-4
+3	-8	-8	-8	-15	-6	+8	+21	+11	+5	+21	-8	-14	-16
-9	-11	+9	+30	+42	+40	+45	+87	+14	-7	+21	-3	-6	+2
-42	-50	-11	-15	+5	+21	+5	0	+9	+21	+18	-15	-21	-5
-8	+12	-11	-30	-33	-40	-8	+1	+5	+15	-9	-32	-11	+16
-10	+52	+48	+7	+30	+34	+31	+19	-14	+3	+10	+9	-9	-30
+12	+14	-22	-19	-20	-13	-8	-2	+9	+20	+18	0	-5	-20
+14	+14	+12	-15	-11	-11	-12	0	+24	-1	-6	+20	-17	-2
+27	+31	+3	-16	-43	-46	-21	+8	-22	-2	+29	+43	+45	+2
+6	+17	+13	-6	+1	-1	+3	+25	+8	-32	-15	+5	+4	-4
+9	+1	-7	-10	-10	-31	-11	0	+4	+3	+20	+15	+11	-13
-21	-11	+22	+19	+14	+16	+9	+26	+1	-12	+18	+17	-3	+14
-16	-34	-58	-55	-7	-22	-53	+11	+3	+43	+25	+17	+17	-12
-62	+18	+39	-77	-74	-112	-62	+122	+19	+33	+135	+55	+16	-48
+19	-102	+103	+312	+373	+411	+114	-105	+61	-18	-289	-204	+70	-8

Lest the criticism may be urged that this selection of groups approximately conforming to a normal curve would reproduce any curve adopted as the model, for a final collection the general law of Table 21 was applied rigorously throughout the same data, *wherein no selection is made by matching*. This is a *tour de force* and an excessive test of the period, the curve, and the deduced law, because it is applied mechanically through sixteen years of data in the magnetic force, the pressure and the temperature, right up to the transition dates, whereas in the periods near the penumbral dates there is likely to be an overlapping of the periodic form, even for some distance, or else a condition where the true normal form is not impressed vigorously upon the earth's field, so that the curves of observation may there be partly fortuitous. As our object is to establish a normal curve and period, the result derived from the general law is merely corroborative of the others. It will require a still further review of the observations to distinguish the best subdivision of the periods, because all the results given in this paper are such as came to hand without knowing what the physical law really was. On Table 27 are collected the various summations under the respective heads, which are self-explanatory after this recital of the procedure followed in the computations. These values are plotted as ordinates on the respective curves, which are plainly marked for intercomparison, charts 21, 22. In spite of many minor divergencies among these curves, the type is clearly discerned, and the adopted form of the normal curve is drawn at the bottom of the D and I type diagrams respectively. By comparison, these curves are found to be the same on inverting one of them. The conclusion is obvious that a typical normal curve underlies the entire system of magnetic and meteorological observations, and that the former precedes the latter in the sequence of cause and effect. (Compare Chart 9.)

CHART 21.—26.68 day solar period, direct type.

CHART 22.—26.68 day solar period, inverse type.

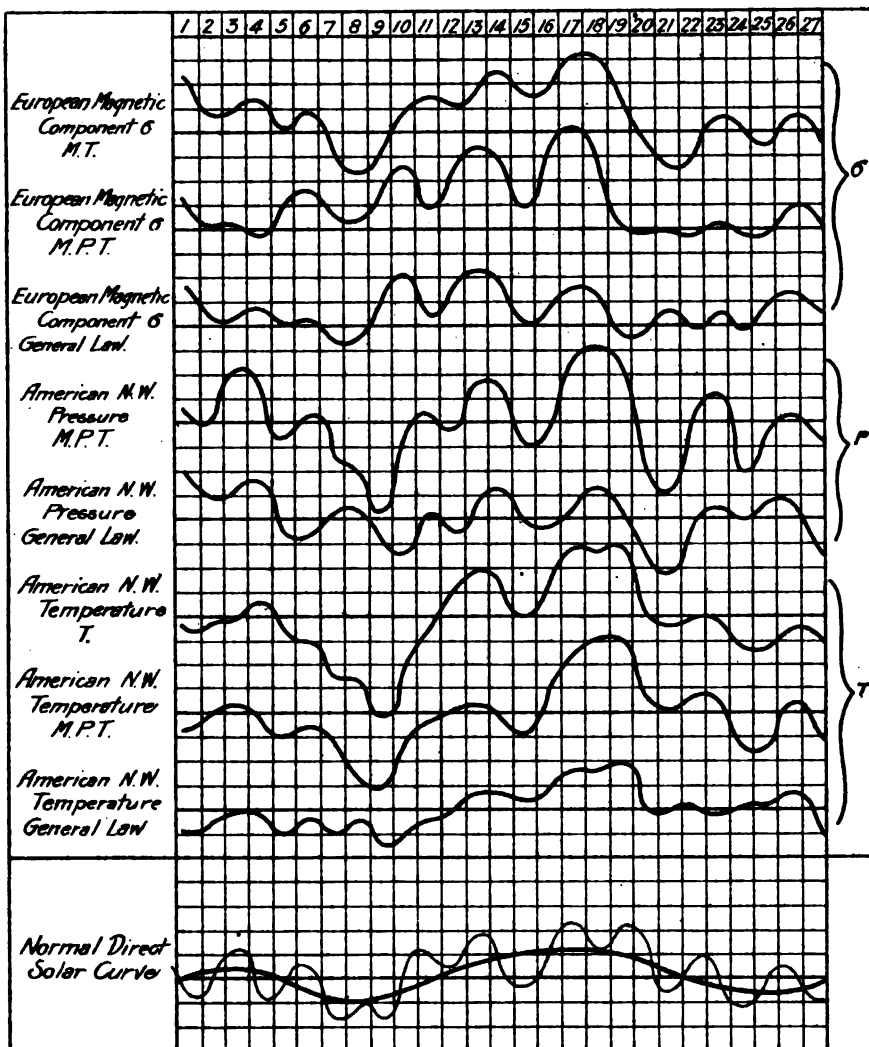


Chart 21.

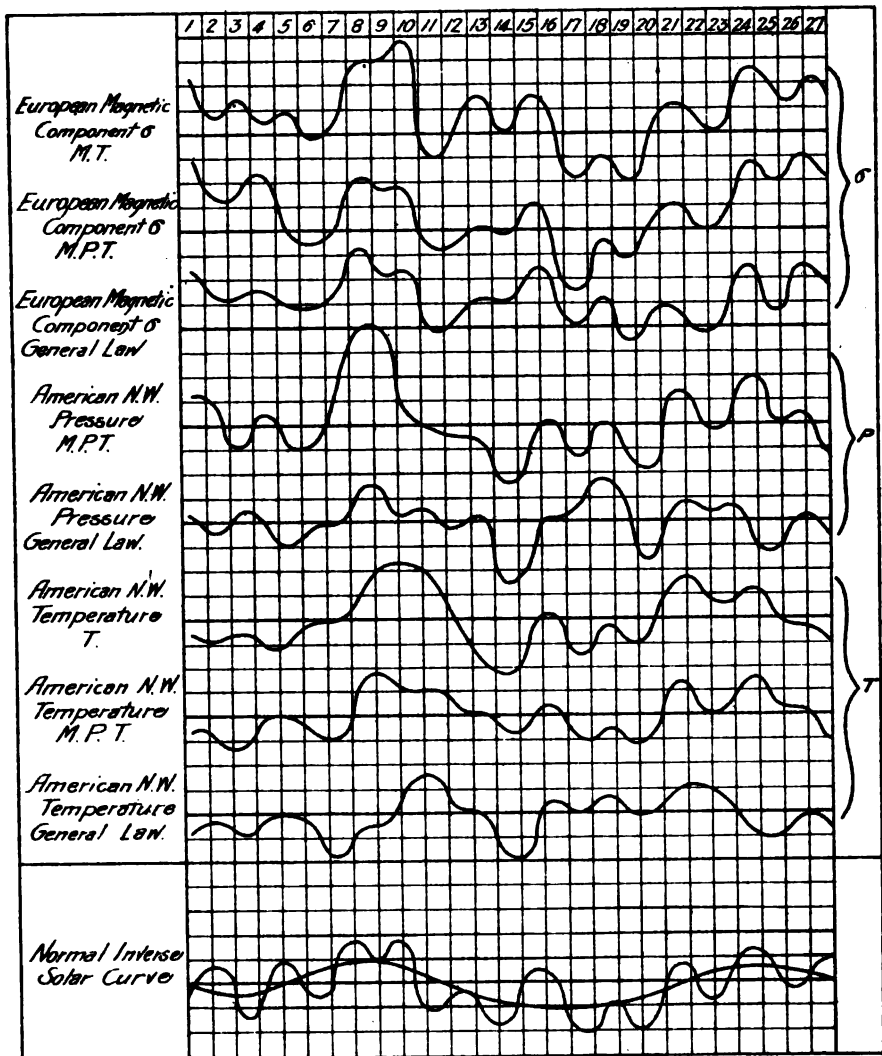


Chart XIII



TABLE 27.—*Determination of the normal solar curve.*

Period.	Direct type.				Inverse type.			
	European magnetic component σ .		Northwest temperature.		American pressure.		Northwest temperature.	
	M. T.		M. P. T.		M. P. T.		M. P. T.	
	M. T.	M. P. T.	T.	Law.	M. P. T.	Law.	T.	Law.
1	+2164	+1007	71	85	+2184	+2902	69	70
2	+761	+348	—	47	+1333	+1315	—	—
3	+1243	+211	—	—	+505	+1505	—	—
4	+1203	+75	—	23	+872	+2371	—	—
5	+124	+119	—	97	—	—	—	—
6	+706	+1693	—	67	—	—	—	—
7	—	+100	—	67	—	—	—	—
8	—	+472	—	67	—	—	—	—
9	—	+544	—	66	—	—	—	—
10	—	+2008	—	86	—	—	—	—
11	+1344	+913	—	43	—	—	—	—
12	+1729	+3115	—	43	—	—	—	—
13	+1583	+3038	—	43	—	—	—	—
14	+1715	+818	—	90	—	—	—	—
15	+1581	+4357	—	52	—	—	—	—
16	+1581	+4201	—	52	—	—	—	—
17	+3085	+2943	—	52	—	—	—	—
18	+1135	+214	—	52	—	—	—	—
19	—	+296	—	52	—	—	—	—
20	—	+1558	—	52	—	—	—	—
21	—	+1477	—	52	—	—	—	—
22	—	+402	—	52	—	—	—	—
23	—	+180	—	52	—	—	—	—
24	—	+281	—	52	—	—	—	—
25	—	+414	—	52	—	—	—	—
26	—	+755	—	52	—	—	—	—
27	—	+773	—	52	—	—	—	—
28	—	—	—	—	—	—	—	—
29	—	—	—	—	—	—	—	—
30	—	—	—	—	—	—	—	—
31	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—
33	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—
36	—	—	—	—	—	—	—	—
37	—	—	—	—	—	—	—	—
38	—	—	—	—	—	—	—	—
39	—	—	—	—	—	—	—	—
40	—	—	—	—	—	—	—	—
41	—	—	—	—	—	—	—	—
42	—	—	—	—	—	—	—	—
43	—	—	—	—	—	—	—	—
44	—	—	—	—	—	—	—	—
45	—	—	—	—	—	—	—	—
46	—	—	—	—	—	—	—	—
47	—	—	—	—	—	—	—	—
48	—	—	—	—	—	—	—	—
49	—	—	—	—	—	—	—	—
50	—	—	—	—	—	—	—	—
51	—	—	—	—	—	—	—	—
52	—	—	—	—	—	—	—	—
53	—	—	—	—	—	—	—	—
54	—	—	—	—	—	—	—	—
55	—	—	—	—	—	—	—	—
56	—	—	—	—	—	—	—	—
57	—	—	—	—	—	—	—	—
58	—	—	—	—	—	—	—	—
59	—	—	—	—	—	—	—	—
60	—	—	—	—	—	—	—	—

The normal curve derived as above when wrapped around a center and developed clockwise, since the sun's rotation is anticlockwise, is shown on Chart 23. In order to present its most symmetrical appearance it may be referred to two rectangular axes, and the origin should then be changed to the middle of the second day of the ephemeris derived from epoch June 12.22. Accordingly a new ephemeris referred to epoch June 13.72, 1887, has been constructed, of which the January dates for the years 1840-1899 are here given. This investigation was conducted by means of the old ephemeris, but it is thought desirable

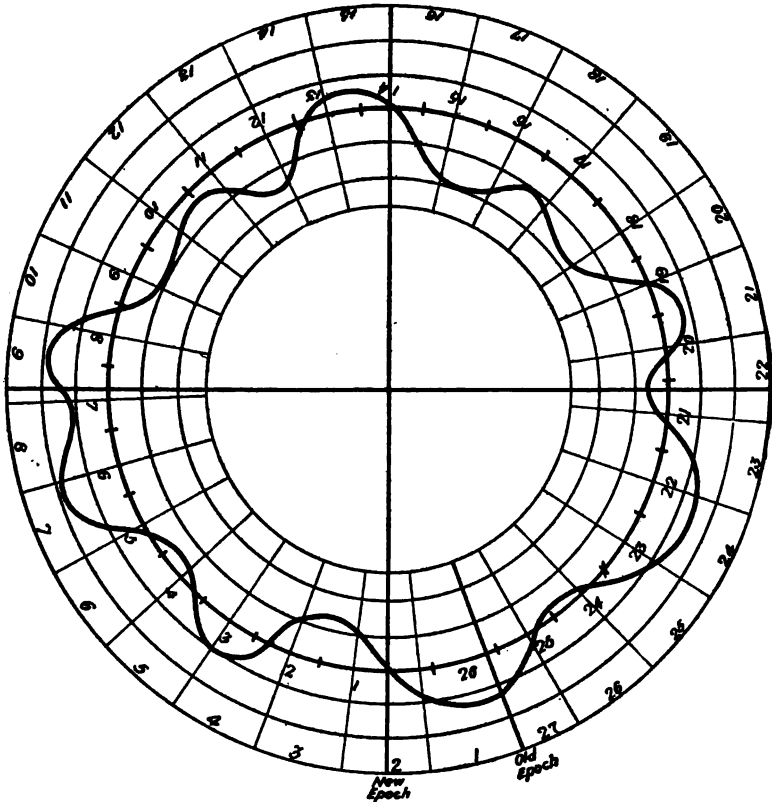


CHART 23.—*Direct type* of the variation of the magnetic and meteorological elements in the 26.68 day period.

Old epoch—June 12.22, 1887.
New epoch—June 13.72, 1887.
Period 26.67928 days.

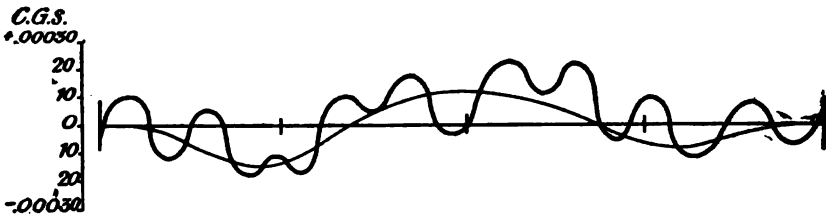
to have the symmetrical type of the curve adopted by others, together with the ephemeris belonging to it. The old curve and ephemeris are found by subtracting 1.50 day from the dates herewith presented in Table 28. The form of the normal periodic curve is also given, and the position of the ends of the rectangular axes are marked along the line of abscissas. For convenience the curve is developed to the right, as the changing aspect of the effect at the earth is thus conveniently presented for study, but it corresponds to an antirotational direction on the sun itself.

TABLE 28.—*Ephemeris of the solar magnetic period.*

[Epoch June 13.72, 1887. Period 26.67928.]

1840.....Jan. 16. 87	1860.....Jan. 21. 99	1880.....Jan. 27. 11
1841.....Jan. 24. 38	1861.....Jan. 2. 52	1881.....Jan. 7. 94
1842.....Jan. 6. 21	1862.....Jan. 11. 33	1882.....Jan. 16. 46
1843.....Jan. 14. 72	1863.....Jan. 19. 84	1883.....Jan. 24. 96
1844.....Jan. 22. 23	1864.....Jan. 1. 67	1884.....Jan. 6. 79
1845.....Jan. 4. 06	1865.....Jan. 9. 18	1885.....Jan. 14. 30
1846.....Jan. 12. 57	1866.....Jan. 17. 09	1886.....Jan. 22. 81
1847.....Jan. 21. 08	1867.....Jan. 26. 20	1887.....Jan. 4. 64
1848.....Jan. 2. 91	1868.....Jan. 8. 02	1888.....Jan. 13. 15
1849.....Jan. 10. 42	1869.....Jan. 15. 54	1889.....Jan. 20. 66
1850.....Jan. 18. 93	1870.....Jan. 24. 05	1890.....Jan. 2. 49
1851.....Jan. 27. 44	1871.....Jan. 5. 88	1891.....Jan. 11. 00
1852.....Jan. 9. 27	1872.....Jan. 14. 39	1892.....Jan. 19. 51
1853.....Jan. 16. 78	1873.....Jan. 21. 90	1893.....Jan. 27. 02
1854.....Jan. 25. 29	1874.....Jan. 8. 73	1894.....Jan. 8. 85
1855.....Jan. 7. 12	1875.....Jan. 12. 24	1895.....Jan. 17. 36
1856.....Jan. 15. 63	1876.....Jan. 20. 75	1896.....Jan. 25. 87
1857.....Jan. 23. 14	1877.....Jan. 1. 59	1897.....Jan. 6. 70
1858.....Jan. 4. 97	1878.....Jan. 10. 09	1898.....Jan. 15. 21
1859.....Jan. 13. 48	1879.....Jan. 18. 60	1899.....Jan. 23. 72

European observations.



Adopted form of the normal periodic curve (direct type).

It may be stated that according to our conception this curve represents the average distribution of a quasi static field surrounding the sun, at the distance of the earth, and therefore it affords the basis for a partial discussion of the state of magnetism within the nucleus of the sun itself, by the spherical harmonic analysis. If the sun maintains this typical field through fifty years without secular change, then the solar nucleus must possess a stability of some sort, quite different from the vaporous condition often assigned by astronomers to the interior of the sun. Agreeing as the 26.68-day period does with the observed rotation of the sun at its visible equator, instead of with the average of the sun-spot rotation, this indicates a circulation of the photosphere like that of the earth's upper atmosphere, at the extremity of a radius of condensation by cooling of the solar material, and thus modifies some other conceptions in solar physics.

Regarding the amplitude adopted for the normal curve, it is simply that which matches the variations of the horizontal component for the latitude of the United States and Europe. Applying it to the total vector s in the same latitude, also to the polar regions, enlarging factors are required which can be readily supplied by the data given in other parts of this paper.

SYNCHRONISM OF THE SAME IN THE 11-YEAR PERIOD.

We now turn our attention to another line of argument to show the synchronous action of the solar and terrestrial elements. It is similar to the data usually given in this connection, such as was collected by van Bebber in *Witterungskunde*, VI Einfluss der Sonnenflecken auf die Witterung, pp. 199-259. It depends upon the tabulations already described, and some additional compilation on the positions of the storm tracks and the movement of storms. The secular changes can not be attributed to any transient or fortuitous combinations of forces, such as the electromagnetic solar radiation which expends its energy in convectional circulations of short duration, while the atmosphere tends back to a state of equilibrium. On the other hand, they must be referred to some long-sustained state of the medium in which the earth is immersed and which affects its temperature and the other conditions of the circulation of the currents of the air as a whole for great periods of time when compared with the variable states observed in the highs and lows of the weather maps. Such prolonged and sustained changes in the magnetic and meteorological elements can never be explained by transient electric currents of the upper atmosphere, and this constitutes an insuperable difficulty toward regarding that theory of the origin of the observed magnetic forces as sufficient. The first objection raised against the theory was that the actual changes in the magnetic field are too rapid and too widely distributed simultaneously over the earth to be due to local currents of the air in any district; the second objection is now added that other values of the forces are too long sustained to be attributed to such a source. The explanation offered in this paper is that the earth lies in a solar magnetic field, which by its unsteadiness causes all kinds of quick variations in the earth's field, and thus accounts for the first class of changes; and that the same solar field goes through long, steady secular changes as suggested by the sun spots and the other allied phenomena. In both the physics is based upon the fact that an increase in the intensity of the magnetic field lowers the temperature of the atmosphere, and thus influences the convective circulation as a whole, but especially in the polar regions. The simplicity of this view and its cosmical efficiency is such as to readily account for the widely diversified effects that have been ascribed to it. A series of secular results is collected on Tables 29, 30 which will be briefly described.

1. From the Carrington, Spoerer, Greenwich, Washington sun-spot observations, the total spotted area, expressed in units of $\frac{1}{100000}$ part of the disk, for each year, was summed up and the result is put in column 2, Table 30. It develops the curve of sun-spot frequency.

2. If the mean of the numbers along each period in Table 20 of the horizontal component σ , and be taken without regard to sign, the values for 1878 and 1882 appear in the respective columns of Table 29. Similar mean values for other years, 1878-1893, are collected in

TABLE 29.
MEAN VALUES OF THE EUROPEAN HORIZONTAL COMPONENT σ .
[Including disturbances. Sixth decimal U. G. S.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	68	73	60	128	95	95	89	113	65	68	75	56	49	65	97	124	.....	82
Feb. 9.3	56	50	73	121	76	106	98	92	98	65	61	63	52	83	162	129	.....	87
Mar. 7.7	61	56	77	79	116	106	83	101	124	92	89	55	55	66	132	91	.....	83
Apr. 3.4	56	48	78	74	153	95	98	85	93	78	88	69	44	78	152	94	.....	86
May 26.7	71	74	91	76	88	91	100	125	97	64	96	66	49	131	120	91	.....	89
June 22.4	73	84	68	91	114	91	82	84	63	62	72	58	45	68	115	93	.....	79
July 19.1	69	70	76	95	103	106	122	112	70	96	72	64	48	66	115	97	.....	86
Aug. 14.8	59	65	143	78	122	98	101	64	93	75	59	56	52	73	109	80	.....	85
Sept. 10.5	50	75	103	69	136	119	102	73	105	77	70	72	66	81	77	130	.....	81
Oct. 7.1	58	103	87	109	126	83	128	103	99	72	70	82	60	128	74	100	.....	94
Nov. 2.8	59	68	100	86	106	98	98	71	92	84	77	91	63	83	110	132	.....	89
Nov. 29.5	83	73	79	106	172	128	108	96	75	70	92	97	46	99	80	86	.....	93
Dec. 26.2	75	86	91	86	126	79	115	90	51	76	60	58	46	85	116	99	.....	84
.....	61	67	.....	73	64	.....	93	121	.....	85	57	.....	40	84	71	.....	74	
Means.....	64	71	85	91	112	99	100	95	88	71	74	68	50	85	111	104	.....	85
Variations.	-21	-14	0	+6	+27	+14	+15	+10	+3	-14	-11	-17	-35	0	+26	+19	.....	

MEAN VALUES OF THE NORTHWEST PRESSURES.

[2900+units in table. Unit=0.01 inch mercury.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	101	104	102	108	115	126	125	122	118	105	123	118	113	113	107	125	117	80.14
Feb. 9.3	90	118	103	94	114	129	118	118	110	114	114	125	104	103	115	111	120	80.12
Mar. 7.7	88	117	95	102	110	98	111	120	109	111	107	108	108	104	105	94	106	80.04
Apr. 3.4	71	93	83	98	92	101	95	100	94	100	105	96	104	97	104	100	98	80.06
May 26.7	91	89	87	83	85	99	89	89	84	91	84	98	83	90	103	89	90	80.04
June 22.4	92	89	87	83	85	99	89	89	84	91	84	98	83	90	103	89	90	80.04
July 19.1	90	91	92	90	91	92	88	87	89	95	82	94	88	93	98	89	91	80.00
Aug. 14.8	94	91	91	96	96	106	99	95	97	106	105	96	101	105	102	91	96	80.05
Sept. 10.5	95	91	103	96	98	108	90	97	98	110	110	105	101	96	95	100	94	80.02
Oct. 7.1	95	107	108	121	101	119	107	107	109	104	108	117	98	109	112	109	96	80.07
Nov. 2.8	100	96	114	114	123	112	123	109	113	114	114	110	115	111	108	109	114	80.12
Nov. 29.5	113	102	102	124	120	132	121	126	113	112	108	100	112	103	121	114	104	80.14
Dec. 26.2	118	83	.....	119	124	.....	115	122	.....	114	117	.....	112	115	117	.....	127	80.16
Means.....	95	98	98	104	105	107	104	106	102	103	106	104	104	103	105	100	103	80.03
Variations.	-8	-5	-5	+1	+2	+4	+1	+2	-1	0	+3	+1	+1	0	+2	-3	0	.....

TABLE 29--Continued.
 MEAN VALUES OF THE NORTHWEST TEMPERATURES.
 [Units in degrees Fahrenheit.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	25	20	15	-3	11	1	6	-2	6	-5	0	8	-4	14	11	-1	8	6
Feb. 9.3	32	19	18	8	18	19	-1	7	19	-6	6	13	9	3	23	14	12	13
Mar. 7.7	41	31	38	23	25	25	13	25	30	23	7	36	12	17	24	32	27	26
Apr. 3.4	45	51	49	30	40	41	36	42	50	36	41	50	38	45	50	44	41	42
Apr. 30.1	50	58	60	53	51	52	50	53	60	52	45	53	47	53	50	58	57	53
May 26.7	61	64	65	65	61	63	61	61	65	62	63	65	66	69	63	71	67	63
June 22.4	72	72	72	67	64	65	68	65	74	70	66	69	70	64	69	73	72	69
July 19.1	75	67	68	70	66	64	65	68	66	69	65	68	71	66	69	69	75	68
Aug. 14.8	71	65	60	68	67	60	65	56	59	63	64	63	63	64	59	62	71	64
Sept. 10.5	58	60	49	52	51	45	56	56	52	57	51	52	56	60	59	45	55	54
Oct. 7.1	46	46	36	40	41	35	49	41	40	44	40	38	50	46	41	39	45	42
Nov. 2.8	40	32	11	28	25	21	32	30	14	36	26	23	35	24	23	15	30	27
Nov. 29.5	23	6	18	25	11	1	21	18	2	11	23	15	27	22	8	11	26	16
Dec. 26.2	5	23	.....	20	-6	.....	-3	1	.....	-4	13	.....	24	0	9	.....	8	8
Means.....	46	44	43	39	37	38	37	37	41	36	37	42	40	38	39	41	42	40
Variations.....	+6	+4	+3	-1	-3	-2	-3	-8	+1	-4	-3	+2	0	-2	-1	+1	+2	.....

MEAN AMPLITUDES OF THE NORTHWEST PRESSURES.
 [Units in hundredths inches.]

Mean dates.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Means.
Jan. 13.6	13	23	24	18	16	19	14	14	11	27	18	12	21	14	14	18	20	17.4
Feb. 9.3	18	27	30	17	17	17	12	12	12	17	17	13	19	19	12	17	25	17.8
Mar. 7.7	21	15	23	11	19	13	10	9	12	16	16	10	24	15	23	17	25	16.9
Apr. 3.4	19	16	16	12	17	16	17	13	14	13	15	19	16	17	12	10	12	14.9
Apr. 30.1	17	16	13	13	14	16	12	14	10	17	14	18	14	12	14	16	15	14.4
May 26.7	9	15	11	9	11	9	12	10	7	11	13	13	13	15	13	10	10	11.2
June 22.4	7	10	12	7	9	12	7	9	6	10	15	9	9	11	10	10	12	9.7
July 19.1	8	8	10	8	9	9	7	6	9	8	9	9	10	9	10	8	8	8.5
Aug. 14.8	9	16	14	7	10	13	10	7	11	9	7	14	9	11	10	14	8	10.5
Sept. 10.5	17	20	14	12	12	13	10	15	16	13	12	18	10	13	13	19	16	13.7
Oct. 7.1	22	22	17	11	18	24	16	11	20	17	11	15	12	15	13	17	15	16.2
Nov. 2.8	18	22	21	19	12	20	11	13	23	14	16	19	13	18	16	19	16	17.0
Nov. 29.5	19	18	18	13	21	24	10	12	15	17	16	13	17	21	10	15	19	16.4
Dec. 26.2	19	19	.....	13	14	.....	16	15	.....	21	15	.....	15	26	15	.....	20	17.3
Means.....	15.4	17.6	17.2	12.1	14.2	15.8	11.7	11.2	12.8	15.0	13.8	14.7	14.4	15.5	13.1	14.8	15.8	14.4
Variations.....	+1.0	+3.2	+2.8	-2.3	-0.2	+1.4	-2.7	-3.2	+1.6	+0.6	-0.6	+0.3	0.0	+1.1	-1.3	+0.4	+1.4	.....

collected on Table 29, the secular and annual means being taken. These are transferred to Table 30, and plotted on Chart 24. Likewise the mean annual temperature of 80 stations in the United States, also of 25 northwest stations, has been computed, the results being similar to those before presented. To conform with the sun-spot curve, the temperature curve is inverted, and the pressure is direct. This means that an increase of solar magnetic intensity is synchronous with a diminution of temperature, but with an increase of pressure, and this function persists throughout every phase of the research. In spite of some irregularity, there is a distinct conformity in the general sweep of these

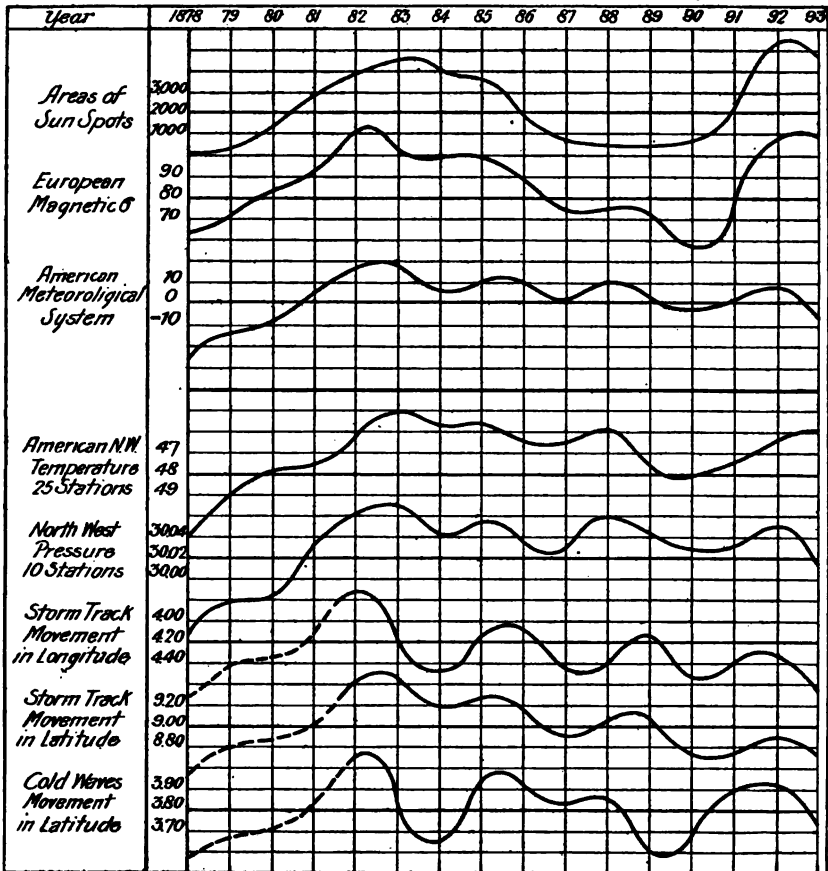


CHART 24.—Diagram of the relative secular variations in the sun spots, the European magnetic field, and the American meteorological system.

curves, and also in the tendency to describe crests during the same years. Indeed, the occurrence of four subordinate crests in the 11-year periods suggests strongly that a $2\frac{1}{2}$ -year period is superposed upon the long sweep of that periodic curve. Apparently this is more at the basis of the seasonal variations of the weather conditions of the United States than anything else, so that in long-range forecasting this period

must be very carefully considered. Unfortunately the great labor of computing the component σ for many years, and the fact that the north-west temperature observations are not complete previous to the year 1878, makes it difficult to trace the variations backward. The lapse of time will, however, enable us in the future to confirm this periodicity, if it persists.

RELATIVE EFFICIENCY OF THE SEVERAL FORCES.

In order to estimate the approximate efficiency of the external magnetic field in affecting the meteorological elements, it is seen, Table 29, that the annual range of temperature was about 60° F., while in the secular period it was about 7° or 8° —that is, one-eighth as large. The magnetic field has probably about one-eighth of the power of the common insolation to change the temperatures of the Dakota region. The action, of course, is very complicated, being propagated through the convectional system, whereby highs and lows traverse that district, but yet its efficiency represents an important though indirect part of the temperature force operating in the interior of the North American continent. In the same way the mean annual range in pressure is about 0.24 of an inch of mercury, while in the secular period it is about 0.08 of an inch—that is, one-third the annual change. I have therefore felt justified in believing that about 25 or 30 per cent of the weather conditions of the Dakota region are very closely connected with the magnetic sources. It may be stated that the application of the ephemeris and periodic curve to the northwest would forecast about 75 per cent of the crests, provided the exact time of inversion of the curve were known in advance. It is this complication which has prevented the scheme having an immediate value for practical work. At present the conditions are not sufficiently well understood to venture on the public forecasts, and I suppose that the required final knowledge of the physical conditions will only come as the result of a long campaign, which implies the establishment of permanent observatories on Northern Rocky Mountain Slope. The total lack of magnetic observations there is a great obstacle to the suitable completion of this research and to securing a practical result.

The annual range in the pressure amplitudes—that is, the extreme tendencies to strong or weak highs and lows, respectively, which are characteristic of the winter and the summer season—is about 0.08 of an inch, while the secular range is about 0.4 of an inch—that is, 50 per cent. One of the most marked features of the study of the curves of magnetic and meteorological elements from year to year is the fact that in some years the curves are turbulent and in others quiet. The gradual change from one extreme to the other, which has occurred several times in the magnetic curves since 1841, leaves the impression that the solar action is persistent, but going through secular variations. To reverse this view, as the theory of upper air electric currents

requires, is unsound, since it implies that the earth's magnetic field influences the sun itself. Unless it can be shown by observations that the electromagnetic field has a secular variation in intensity, these slow changes can not be referred to that radiation as their cause. This has never been done, the results of observation being negative. On the other hand, the observational proof of the variation of the direct magnetic field is clear and of a kind to accord with the nature of the observed effects. The annual range in temperature amplitudes is about 6° F., and the secular range about 1° . The data appears on the twelfth column of Table 30.

An extensive computation of the location of the mean tracks of the highs and lows of the United States, whose results are mentioned in Bulletin No. 20 of the Weather Bureau, has been executed, to the following effect. The mean position of the highs and lows as they drift eastward go through a series of accelerations and retardations; also the mean tracks change their location, as a whole, in latitude. This computation includes the cold-wave tracks. The result is placed in columns 6-11 of Table 30. The value of the units in inches is indicated, and the fact that the longitude curves are inverted, while the latitude curves are direct. This means that in years of increased magnetic impulse the tracks lie farther north and the eastward movements are slower by the amount indicated, the extremes being about 150 miles east and west and 40 miles north and south for the highs and lows; the cold-wave tracks are more to the north in the stronger magnetic years. The curves conform to the type set by the magnetic curve and should individually be compared with it. If it be assumed that each of the individual curves here brought forward from the American meteorological system, is a more or less accurate measure of the action of that force which causes the changes synchronously in all the elements, then the mean of the ordinates of these meteorological curves will furnish the average type, which is given in the last column of Table 30, and the third curve of Chart 24. A comparison of this mean American meteorological curve with the European magnetic curve, certainly shows conformity to such an extent as to exclude merely accidental physical relations. Should such a result be obtained also in the future, it will be a demonstration of the synchronism of the two systems of forces under consideration.

TABLE 31.—*The solar magnetic force, West Indies hurricane frequency, movement in longitude, and number of highs and lows in the 26.68-day period.*

Days of the 26.68-day period.																										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Normal variations of the solar magnetic force.																										
-6	-4	+12	-8	-5	+5	-16	-11	-17	0	+12	+5	+19	+5	-4	+5	+23	+13	+20	+17	-6	+8	+4	-13	-5	+4	-10
West Indies hurricane frequency for the years 1874-1893.																										
3	6	5	4	4	5	7	3	5	10	5	5	6	5	1	11	9	6	5	5	5	6	2	4	7	7	3
Relative mean daily movement in longitude of U. S. highs and lows.																										
+2.0	+1.1	+0.7	-1.0	-0.5	+1.8	+1.9	+0.5	-2.3	-0.6	-0.3	-1.0	+1.9	-2.1	-0.3	+0.3	-0.4	+0.7	+0.3	-0.2	-0.8	-0.2	-0.8	-0.8	-1.7	-1.4	.....
Relative numbers of highs and lows in the Northern Hemisphere, 1883 and 1887.																										
14	10	31	18	11	27	17	21	23	15	31	36	39	42	38	38	41	45	34	34	33	32	23	25	32	27	29

SOME MISCELLANEOUS DATA SHOWING SYNCHRONISM IN THE 26.68-DAY PERIOD.

It is, perhaps, unnecessary to adduce more evidence of the interdependence of these forces; but it may be stated that one can hardly attack any of the meteorological problems by means of the 26.68-day period, provided that the eastward drift be allowed for with the accompanying convectional changes, without reproducing the normal curve with some degree of precision. Usually it requires many observations to do so; but this is, of course, due to the necessity of separating indirectly the two closely interwoven systems. In the magnetic field, the auroras, and the earth's currents the time correction is not needed. In the extreme northwest the time is the same; but everywhere else

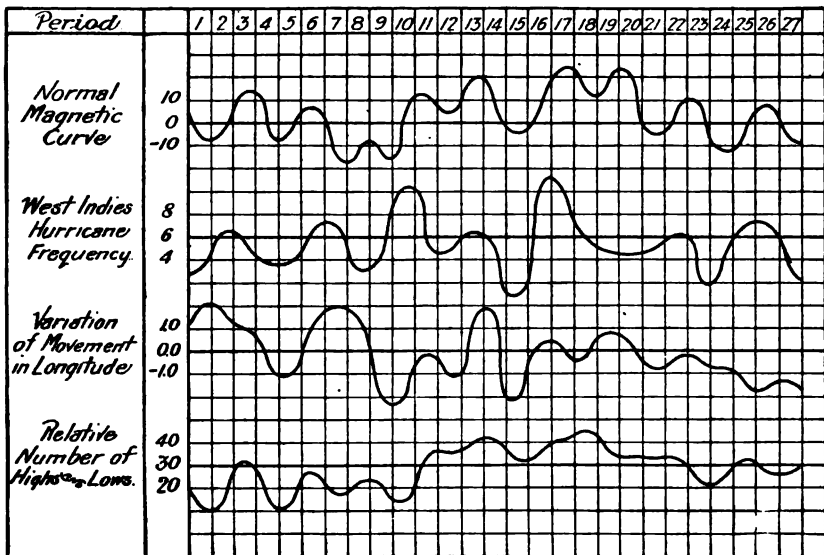


CHART 25.—Diagram of the magnetic force, hurricane frequency, movement in longitude, and number of highs and lows in the 26.68-day period.

the ephemeris must be adjusted for longitude to the place of operation. As further examples we may incite the following curves of Chart 25 from the values collected on Table 31.

No. 1 is the typical solar magnetic curve already found. No. 2 is the relative frequency of the occurrence of the West Indies hurricanes for the years 1874–1893, as given in Table 31, and it shows a tendency to form such storms along with the increase of the magnetic impressed force. No. 4 is the curve of the relative frequency in the number of high and low centers counted on the International Charts for 1883 and 1887. It displays the same general impulse. Apparently the entire hemisphere at certain dates breaks out into more rapid circulation, whereby the large highs disintegrate into smaller parts, and the number of cyclonic centers is at the same time increased. From the

tabulations of the positions of the storms tracks of the United States when collected in the 26.68-day period, the summary in curve No. 3 shows a tendency to produce the same fundamental curve as the magnetic impulse.

It is seen from the foregoing exposition of the data that the synchronism between the magnetic field and the meteorological elements persists from day to day, in short and in long periods, and under a great variety of geographical conditions. Reasons have been given for accepting the view of the direct solar magnetic action, based upon the direction of the impressed vectors, their periodicity in a rotation time agreeing with that of the sun at its equator, and also in the 11-year period of the sun-spot frequency. It was shown that the arguments usually accepted as decisive against direct action are partly misconceived by reason of the mistaken identification of the observed diurnal variations with the direct polar field of the sun, while our exposition shows that these belong to the electro-magnetic field, and not to the direct field at all. Compare the argument of Chambers reviewed in Chapter 1, page 17. The extreme difficulty of assigning to hypothetical electric currents of the upper atmosphere such sources and activities as will account for the operation of the magnetic variations over the entire earth simultaneously in short and long impulses, as well as the impossibility of transmitting the observed changes on the earth to the sun in order to explain the observed operations there, influences us to advocate the direct magnetic action of the sun as the cause, while the atmospheric currents of electricity and the convectional currents are synchronously dependent upon it. There is no disposition to minimize the efficiency of the tropical insolation in its effects upon the atmosphere, but merely to supplement it with such forces as are called for by known facts, in order to explain fully the entire range of the phenomena of terrestrial magnetism and meteorology.

CHAPTER 6.

SOLAR MAGNETISM.

THE SOLAR CORONAS OF JULY 29, 1878, JANUARY 1, 1889, DECEMBER 22, 1889.

Having reviewed the material at our disposal analyzed to show the variations of the terrestrial magnetic field and the synchronous changes among the meteorological elements of the atmosphere, it is fitting to collect such evidence as we possess of the magnetic state of the sun itself. The strongest line of argument is of course the one traversed, namely, that there is an impressed external field of force within the earth's field whose representative curve is periodic, the period agreeing very closely with the well-known visible rotation of the sun's photosphere at its equator. The explanation of the inversion of type of the impressed field, to be taken up in the course of this chapter, constitutes the most uncompromising evidence in favor of the view that the direct action of the sun's magnetic force is at the basis of the observed variations of the earth's magnetic field, other than the diurnal variations and the annual changes peculiar to these.

It is proper to recall that this investigation had its beginnings in a study of the rays of the solar corona, visible during eclipses, and that the proposition then was to explain their apparent curvature by the equation representing the lines of force of the magnetic field surrounding a spherical magnet. The leading results will be mentioned here, but without the details contained in the original papers.* On charts 26, 27, 28 are seen the diagrams of the coronas of the eclipses July 29, 1878, January 1, 1889, December 22, 1889, plotted as dotted lines. These eclipses occurred near the minimum of the sun spot disturbances, Chart 30, and such occasions seem to be the only ones when the sun is sufficiently quiet to exhibit the normal, undisturbed state of its typical system. Other eclipses give very confused pictures of coronal lines, and are unsuited for studying the problem in hand. The lines appearing on a photograph of the corona are of course rifts in the material surrounding the sun, seen projected on a plane perpendicular to the line of sight. A magnetic solar field may have the power to arrange this material approximately along the lines of force, just as is the case with the iron fillings used in tracing out a field around a steel magnet.

* Compare Amer. Journ. Sci., Nov., 1890; July, 1891. Astron. Soc. Pac., No. 14, 1891; No. 16, 1891. The Solar Corona. Smithsonian Institution, 1889.

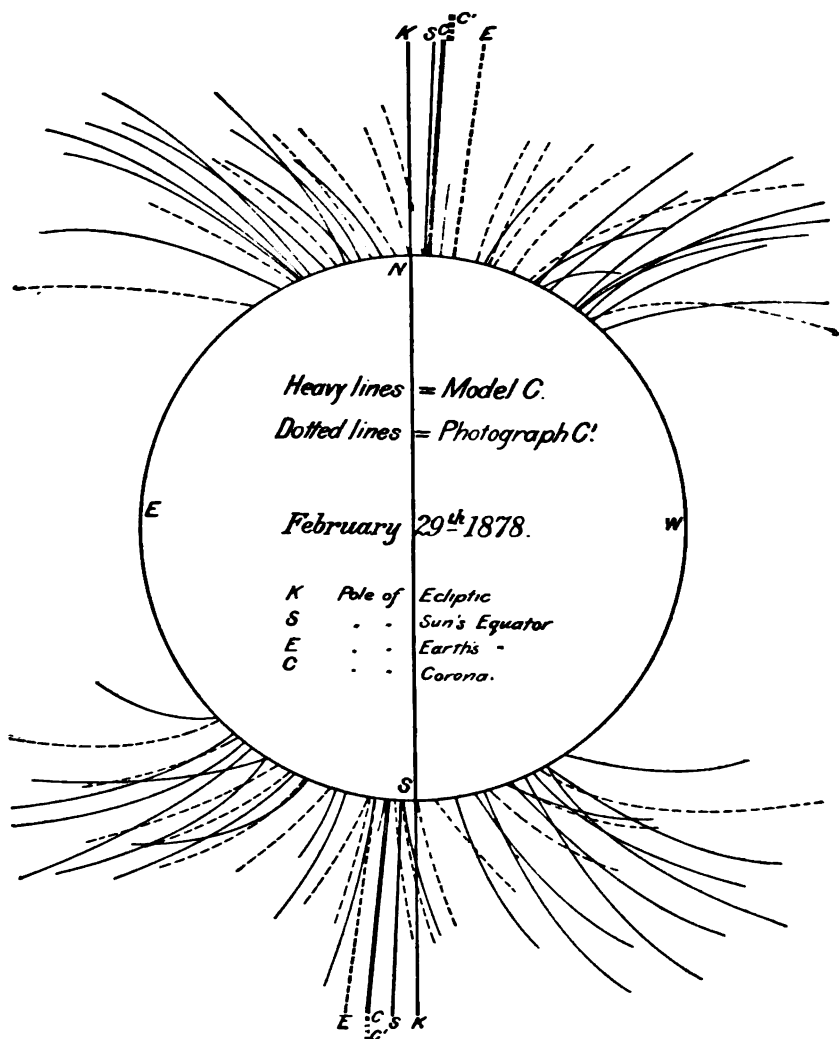


CHART 26.—Comparison of the model with the coronal lines for the eclipse, July 29, 1878.

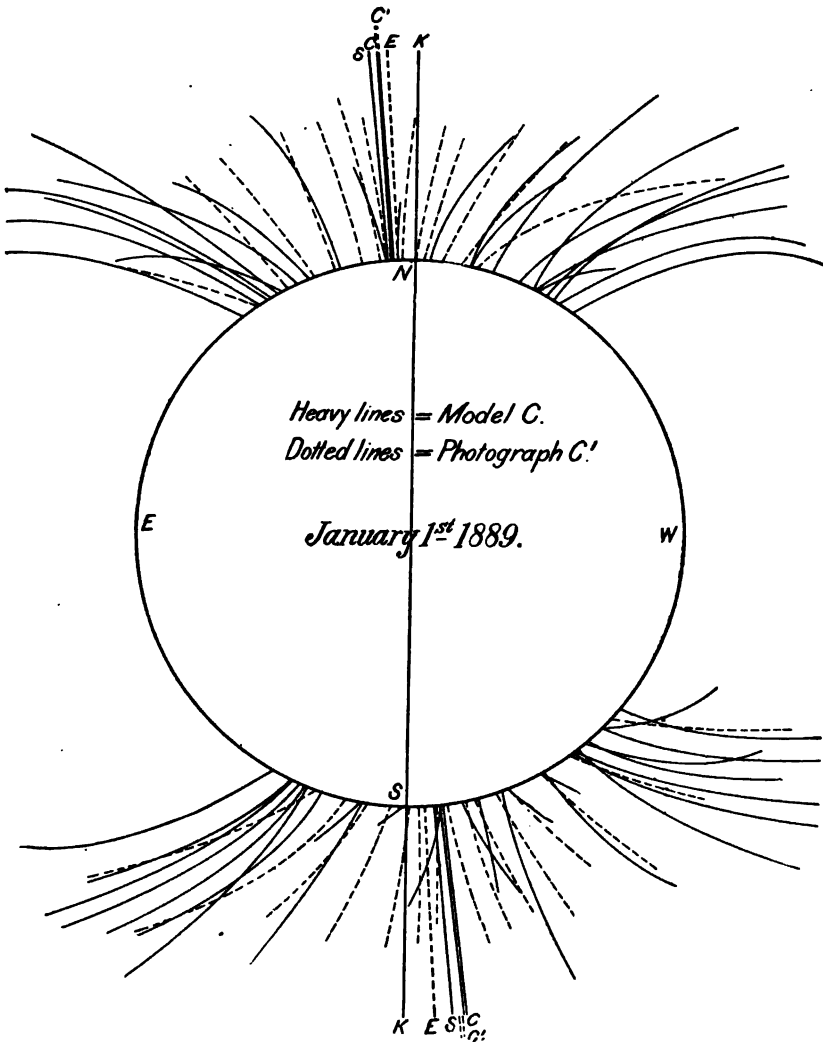


CHART 27.—Comparison of the model with the coronal lines for the eclipse, January 1, 1889.

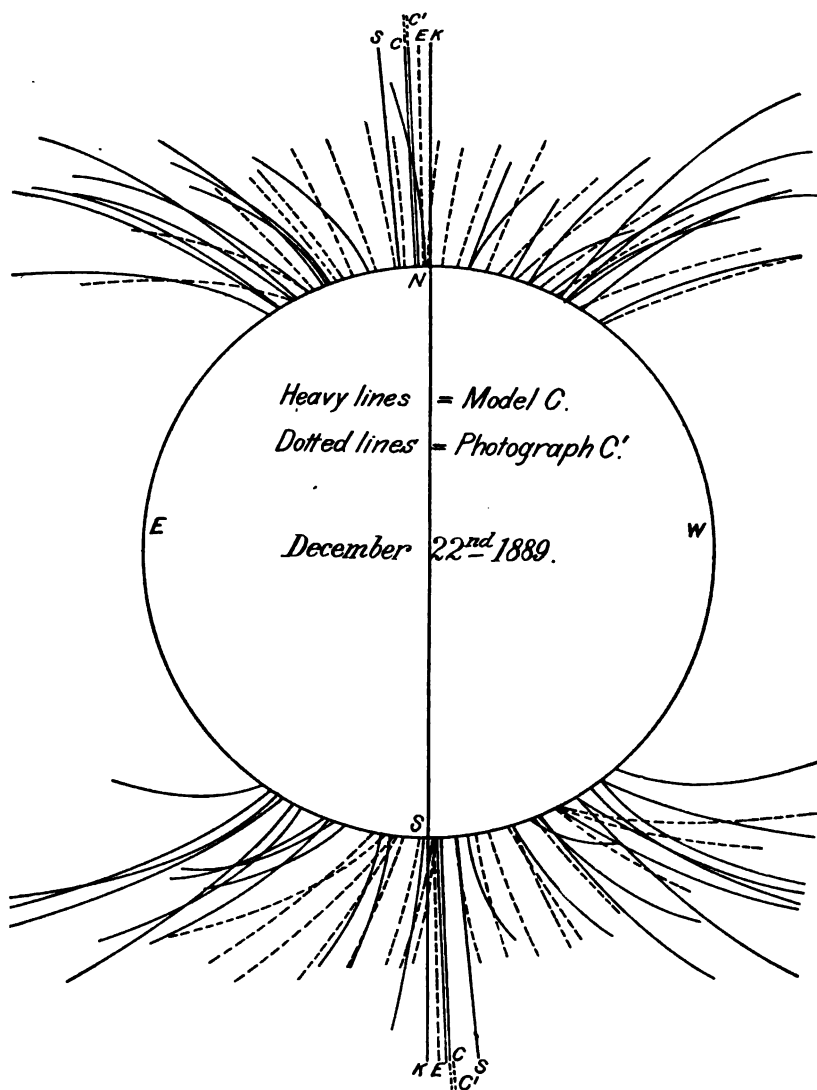


CHART 28.—Comparison of the model with the coronal lines for the eclipse, December 22, 1889.

Hence, these visible lines can be employed in discussing the geometrical system thus mapped out. The dotted lines on the charts simply reproduce the available rifts traced on the negatives, and in this respect they merely stand for the original photographs taken during the eclipse.

$$\text{Equation of the lines of force, } N = \frac{8\pi \sin^2 \theta}{3r}.$$

The measured line is that projected from its true position in space upon the plane through the center of the sun, perpendicular to the line of sight. From the coordinates (r, θ) of points on the photograph of an individual ray we compute the corresponding values on the ray itself before projected from the original plane, which makes the angle α with the plane of projection.

$$\begin{aligned} x &= r \sin \theta. \\ y &= r \cos \theta. \\ r &= \sqrt{x^2 + y^2}. \\ \sin^2 \theta &= \frac{x^2}{r^2} = \frac{x^2}{x^2 + y^2}. \end{aligned}$$

As a first approximation, suppose the axis of the sun to be perpendicular to the plane of the ecliptic, so that the projected point would move across the disk during rotation in a line parallel to the ecliptic.

X Y = true position.

$r \sin \theta$ = radius of revolution.

$$x = X \cos \alpha = r \sin \theta \cos \alpha.$$

$$y = Y.$$

$$N = \frac{8\pi}{3} \cdot \frac{x^2}{(x^2 + y^2)^{3/2}} = \frac{8\pi}{3} \cdot \frac{r^2 \sin^2 \theta}{(r^2 \sin^2 \theta \sec^2 \alpha + r^2 \cos^2 \theta)^{3/2}}.$$

Since the coordinates (r_1, θ_1) , (r_2, θ_2) , (r_3, θ_3) are assumed to belong to the same line of force, we have,

$$\frac{r_1^2 \sin^2 \theta_1}{(r_1^2 \sin^2 \theta_1 \sec^2 \alpha + r_1^2 \cos^2 \theta_1)^{3/2}} = \frac{r_2^2 \sin^2 \theta_2}{(r_2^2 \sin^2 \theta_2 \sec^2 \alpha + r_2^2 \cos^2 \theta_2)^{3/2}}.$$

Take for abbreviation, $X_1 = r_1 \sin \theta_1$; $X_2 = r_2 \sin \theta_2$

$$Y_1 = r_1 \cos \theta_1; \quad Y_2 = r_2 \cos \theta_2,$$

and we obtain,

$$\sec^2 \alpha = \frac{X_2^{4/3} Y_1^2 - Y_2^2 X_1^{4/3}}{X_1^{4/3} X_2^2 - X_2^{4/3} X_1^2}.$$

TABLE 32.—Computed polar distance of the base of the visible rays of three coronas.

Corona of July 29, 1878. [Quadrants of rays.]					Corona of January 1, 1889. [Quadrants of rays.]					Corona of December 22, 1889. [Quadrants of rays.]				
N.E.	N.W.	SW.	SE.		N.E.	N.W.	SW.	SE.		N.E.	N.W.	SW.	SE.	
1 30.40 2 28.35 3 28.43 32.55 30.59 31.8 33.39 30.32 32.41 31.32 33.25 33.18 34.34 36.23 35.16 42.23 40.16	1 33.5 30.17 30.2 28.2 27.41 26.11 36.30 34.5 32.5 34.52 33.30 32.26 30.17 31.25 32.26 32.26 35.0 33.5 34.23 33.5 31.29 41.55 41.58 40.49	1 35.0 30.21 23.22 31.23 30.44 33.59 32.26 34.1 30.17 31.25 32.26 32.26 35.0 33.5 34.23 33.5 31.29 41.55 41.58 40.49	1 31.41 32.25 20.28 30.23 32.34 34.25 34.59 31.48 33.45 34.1 31.38 34.19 33.25 34.34 32.38 35.8 33.13 35.11 38.11 38.39 37.26		1 37.36 33.46 33.20 27.19 29.44 26.18 34.45 24.28 34.5 32.7 17.51 17.35 31.17 34.19 30.53 31.29 38.0 38.25 37.3 43.11 42.17	1 30.22 29.49 30.1 30.34 27.59 32.7 33.1 31.7 32.7 33.48 31.0 33.7 34.1 31.57 34.31 34.36 33.33 31.17 80.4	1 32.8 32.39 30.42 31.1 29.0 29.27 31.29 32.16 30.53 30.27 30.41 29.25 34.27 35.10 33.26 20.25 29.29 29.5 7.37.49 35.53 36.28 42.55 43.11 42.2	1 31.44 32.40 31.11 27.47 27.4 27.17 29.56 30.14 29.51 32.24 33.8 31.17 33.23 33.55 32.46 34.50 33.10 34.53 35.31 32.55 37.49 43.11 35.30		1 28.33 29.27 28.33 25.7 24.58 25.28 29.0 29.0 28.59 26.0 25.59 26.4 34.1 34.22 34.13 34.32 33.40 34.23 34.31 38.22 38.43 28.37 28.48 35.59 36.0 35.47 38.7 38.24 37.31	1 30.50 32.21 30.33 28.9 27.12 26.37 28.14 28.11 28.18 26.96 27.15 26.46 28.58 29.2 34.33 34.50 33.52 36.40 36.38 36.31 37.55 37.25 36.5 36.5	1 31.35 31.30 31.26 32.4 33.39 30.4 31.46 31.53 31.24 31.16 31.19 31.6 32.35 32.44 33.4 33.1 32.12 30.33 30.38 33.41 33.66 32.29		
33.41	33.36 33°.59'	34.21	34.16		31.8	31.50 32°.13'	33.19	32.35		30.57	32.6 31° 41'	31.38	32.3	

If θ_0 is the angular distance from the coronal pole at which the ray reaches the surface of the sun, in the plane making the angle α with the plane of the disk,

$$\sin^2 \theta_0 = \frac{x^2 \sec^2 \alpha}{(x^2 \sec^2 \alpha + y^2)^{1/2}},$$

The detailed results of the computation may be found in the publications of the *Astronomical Society of the Pacific* (Vol. III, No. 16, 1891). The value of θ_0 for each measured ray, in the several quadrants of the three coronas specified, are reproduced in Table 32. An inspection of these angles, from the base of the rays to the poles of the sun—more properly to the pole of the magnetic system—shows that there is a remarkably persistent law, according to which these rays spring from the sun in a narrow belt 10° or 15° wide, whose central circle is $32^\circ 38'$ polar distance for these coronas. The corona bases of 1889 are on the average about 2° nearer the poles than those of 1878. It may be observed that these results do not favor the view that the base of the visible coronal rays lies within the sun-spot belt. Hence any theory depending upon that supposition must draw upon other observational data than that immediately under consideration for its support. If the confused mass of rays, usually seen along the equatorial regions of the sun, proceeds from lower latitudes than the coronal belt, as they should according to this scheme of magnetic lines of force, then their individuality is lost in the superposition caused by the optical projection. The massing of the coronal lines in the well-known four quadrantal protuberances is naturally explained by the geometrical distribution here advocated; the open array of the rays in the polar regions is also likewise accounted for conformably with it. Why the rays should develop separately along the belt indicated is not understood. The analogy with the terrestrial auroral lines is very plausible, but probably misleading, since, according to the exposition in an earlier chapter, those were due to the action of a permeable shell placed in an external field of magnetic force; but we can connect the sun with no such independent exterior field.

Continuing the detailed computation referred to in the paper of the A. S. P., it was found that the poles of the corona appeared to be 4.5° from the sun's poles; also separated by about 100° in longitude, the south pole preceding. The computation in the same paper regarding the period of rotation proves to be incorrect, because the wrong number of revolutions was assumed between January 1 and December 22, 1889. It should have been 13 instead of 12. This subject may be taken up again some time, especially if another satisfactory photograph of the corona, showing separate coronal lines, can be secured.

A model of the coronal streamers was now constructed from this data, by inserting wires on a ball 5 inches in diameter along two belts, one in either hemisphere, at the mean polar distance of 33° , measured from two points taken as the poles of magnetization. These are located 5°

from the axis of rotation of the ball, the lower 100° in advance of the upper. The wires have the curvature conforming to the lines of force at the given polar distance as developed from the ordinary formula. The ball was then mounted on a stand whose base represents the plane of the ecliptic, having an axis inclined at 7° to that plane. If this is in reality a counterpart of the sun's coronal structure, then it is only necessary to locate the ball in agreement with the relative positions of the sun and the earth at the eclipse, assuming that the south coronal pole is on the central meridian of the sun at the beginning of the periods of the 26.68 day ephemeris. These positions of the sun and earth can be found on the accompanying Table 33 for seven eclipse dates. At any date corresponding to the day of the ephemeris beginning a new period, as given in the third line of the table, the south coronal pole should be central on the sun toward the earth; at any other date proportionately advanced. The direction of the earth from the sun, relative to the axis of rotation, at any date is well known from the spherical triangle K. S. E. Hence the model can be set according to this provisional data for any desired epoch.

TABLE 33.—*Computation of the longitudes of the coronal poles at seven eclipses between 1878 and 1893.*

Year.	1878.	1882.	1883.
	d h m	d h m	d h m
Date of eclipse, G. M. T	July 29 9 23	May 16 10 42	May 6 9 45
Do	July 29.39	May 16.62	May 6.41
Next preceding epoch	July 14.26	May 1.32	Apr. 13.46
Elapsed interval, days	15.13	15.50	23.95
Elapsed interval, degrees	219.1	224.4	346.8
Longitude of sun	112.2	41.3	23.8
Reduction to heliocentric longitude	180.0	180.0	180.0
Approximate heliocentric longitude of S. coronal pole	161.3	85.7	190.6
Approximate heliocentric longitude of N. coronal pole	55.3	339.7	84.6
Heliocentric longitude of the earth at the eclipse	306.6	236.3	226.0

Year.	1886.	1889.	1889.	1893.
	d h m	d h m	d h m	d h m
Date of eclipse, G. M. T	Aug. 29 0 59	Jan. 1 0 16	Dec. 22 0 53	Apr. 16 2 27
Do	Aug. 29.04	Jan. 1.39	Dec. 22.04	Apr. 16.10
Next preceding epoch	Aug. 22.74	Dec. 23.50	Dec. 5.34	Apr. 15.60
Elapsed interval, days	6.30	8.89	16.70	0.50
Elapsed interval, degrees	92.5	128.7	241.8	7.2
Longitude of sun	150.0	272.7	254.1	26.8
Reduction to heliocentric longitude	180.0	180.0	180.0	180.0
Approximate heliocentric longitude of S. coronal pole	62.5	221.4	315.9	214.0
Approximate heliocentric longitude of N. coronal pole	316.5	115.4	209.9	108.0
Heliocentric longitude of the earth at the eclipse	336.0	101.7	90.9	206.8

This was accordingly done for the three coronas under discussion; then the model was projected upon a screen, and the lines of the wires carefully traced on paper. Finally these projected lines, including the poles of the sun's axis, earth's axis, axis of ecliptic, and the coronal

poles, S. E. K. C. respectively, were superposed upon the drawings of the eclipse, previously described as the dotted lines, where they appear on the charts 26, 27, 28 as heavy solid lines. Of course, the poles K. S. E. are located with no uncertainty, the only question pertaining to this investigation being the agreement of the poles C C' of the model and photograph respectively. These are given as double lines, and it may easily be seen that their coincidence under three such diverse conditions is remarkable, taking both hemispheres into consideration. The line C is the axis of the model, located by computation only and therefore mechanically placed, since it may be predicted for any date, according to the ephemeris. The line C' was drawn upon the eclipse photograph, and it is that line to which the central polar ray is apparently tangential, allowing a balanced curvature of the other rays on either side, by means of which a polar point was selected, and from which all the polar angles on the photograph were measured with the engine of the Transit of Venus Commission.

An intercomparison of these three charts shows a conformity in many respects between the model and the photograph of the corona which is interesting. There are some gaps in the available measured lines of the photographs, as the N. W. quadrant, January 1, 1889, and the S. E. quadrant, December 22, 1889, where the density of the light on the negative was too continuous to trace any rifts. Yet on the whole, it is instructive to find that the same model, constructed on a definite geometrical plan, should, by merely turning it into positions fixed by astronomical coordinates, agree even to this extent with the corona pictures. This is especially true of the poles C C'; of the accumulation of the rays to the right or left of the axis of the ecliptic K; and finally of the trend of the individual rays. One can be easily convinced that this conformity is not accidental by changing the location of the wires on the ball or by changing the assumed rotation period of 26.68 days.

Concerning the corona of 1893, for whose position I made a prediction, published in *Astronomy and Astrophysics* No. 119, it may be said that the photographs of that eclipse, kindly loaned by the Lick and the Harvard College observatories, were not such as to admit tracing out with certainty the coronal axis. This was due to the character of the corona occurring at the sun spot maximum, when the force producing the rays was apparently very turbulent; and to the fact that the rays were much burned on the film of the gelatine dry plate near the disk, whenever they were also taken at a distance from the moon's disk. It would be better to use wet plates in order to secure the same ray through a long radial distance. Composite rays are not adapted to accurate measurements without preliminary adjustments, which must be embodied in the computations. It seemed probable, however, on examination, that the axis of the corona as seen at the eclipse was on the side of the axis of the ecliptic required by my forecast, but the assertion could hardly be ventured. On the whole, viewing the entire

TABLE 34.—Sun-spot areas distributed in the 26.68-day period.

NORTHERN HEMISPHERE.

Year.	1	2	3	4	5	6	7	8	9	10	11	12	13
1854.....	2	2	22	70	17	10	9	2	9	0	28	57	5
1855.....	0	0	14	23	17	0	0	25	0	0	0	0	0
1856.....	0	6	0	0	2	0	15	70	0	2	4	0	0
1857.....	70	0	0	49	10	33	35	16	16	45	50	0	30
1858.....	18	52	106	119	135	112	49	18	64	65	190	152	78
1859.....	74	63	77	76	59	121	78	39	82	148	36	39	102
1860.....	213	104	80	220	208	83	115	138	199	150	79	98	83
1861.....	25	120	90	78	208	84	174	185	85	115	115	30	41
1862.....	10	80	40	10	36	85	51	95	85	135	94	28	70
1863.....	26	80	10	28	19	60	57	0	30	122	185	210	140
1864.....	6	0	45	20	20	87	77	120	2	34	78	110	97
1865.....	2	39	42	23	57	32	43	25	62	0	25	20	47
1866.....	0	20	10	0	5	20	64	5	8	5	40	12	16
1867.....	0	0	0	29	0	8	6	5	5	0	0	9	0
1868.....	30	55	54	119	25	35	58	95	44	18	31	9	24
1869.....	120	61	65	175	83	45	100	44	40	123	101	46	87
1870.....	127	210	68	120	151	165	235	135	92	65	57	18	121
1871.....	123	30	28	44	60	18	84	92	65	113	74	88	74
1872.....	59	55	113	148	45	123	95	140	92	314	49	53	8
1873.....	30	18	107	56	20	29	20	29	159	22	111	50	0
1874.....	55	10	26	87	11	58	6	2	15	65	24	57	73
1875.....	45	27	3	0	12	20	0	4	18	26	2	0	22
1876.....	0	0	0	6	8	7	0	2	0	4	4	30	5
1877.....	30	0	0	0	4	0	0	59	30	90	30	20	0
1878.....	8	10	4	0	0	0	0	5	0	0	0	12	0
1879.....	3	0	5	0	0	45	31	0	2	0	15	4	0
1880.....	30	6	13	36	1	1	2	52	3	52	25	177	0
1881.....	120	32	70	66	12	31	85	2	36	69	43	114	83
1882.....	6	17	69	38	54	22	21	206	68	2	51	58	3
1883.....	8	70	74	63	1	23	33	83	3	0	11	59	23
1884.....	15	77	103	89	215	194	141	163	15	47	25	78	53
1885.....	172	39	1	0	11	1	7	76	202	43	75	17	7
1886.....	93	6	0	0	15	2	7	7	14	28	0	10	6
1887.....	1	5	12	26	18	9	0	1	4	1	1	4	2
1888.....	0	0	0	4	1	15	0	3	0	19	34	0	0
1889.....	0	0	2	4	0	0	0	0	0	0	0	0	0
1890.....	0	11	60	0	13	5	7	0	1	2	2	41	0
1891.....	81	68	5	175	28	60	24	64	67	36	64	24	54
Sum.....	1,602	1,373	1,518	2,001	1,581	1,643	1,729	2,007	1,617	1,960	1,753	1,734	1,354
Variation...	-49	-278	-133	-350	-70	-8	+78	+356	-34	+309	+102	+83	-297

TABLE 34.—*Sun-spot areas distributed in the 26.68-day period.*

NORTHERN HEMISPHERE.

14	15	16	17	18	19	20	21	22	23	24	25	26	27	Sum.
3	78	20	28	20	17	53	44	34	14	12	0	22	8	584
0	0	0	0	10	11	0	5	0	0	14	16	0	0	135
4	25	0	0	5	0	8	9	0	38	17	5	0	0	208
19	0	0	20	2	48	39	12	0	10	52	25	33	48	662
47	30	43	80	65	145	47	25	14	87	177	62	81	4	2,065
103	140	46	44	106	161	39	49	50	83	30	38	36	57	2,066
63	31	154	85	154	48	117	228	142	72	159	255	111	90	8,479
50	0	155	141	10	20	39	122	100	115	105	83	31	0	2,321
100	25	120	40	8	14	30	23	43	40	52	26	160	34	1,534
16	95	20	101	50	45	90	91	75	25	55	10	125	15	1,780
40	60	40	0	20	32	112	42	10	40	65	100	80	32	1,369
20	0	124	66	50	15	39	50	77	219	67	41	59	29	1,273
0	0	23	10	15	14	23	23	14	19	10	0	6	0	419
0	32	40	0	30	8	0	18	39	70	0	0	6	0	305
60	146	30	50	18	0	15	35	60	10	40	23	43	8	1,135
118	75	94	110	140	63	90	170	68	93	91	20	15	96	2,383
108	130	65	82	57	105	106	233	100	57	190	230	103	126	3,256
114	95	160	82	129	54	25	46	63	80	101	217	87	95	2,241
58	69	134	65	169	109	33	125	172	125	140	110	61	110	2,874
12	70	25	57	63	57	23	6	56	76	6	22	65	58	1,247
38	7	5	40	4	6	38	2	46	31	20	28	24	34	812
0	41	37	1	6	12	4	0	20	27	14	2	17	18	378
2	2	0	0	22	0	0	0	4	0	10	7	0	5	118
0	0	0	35	0	4	40	0	15	0	0	0	0	30	387
2	0	0	3	0	0	0	0	0	0	0	3	0	0	42
2	3	0	0	20	0	0	0	0	0	0	3	0	5	138
5	79	0	171	46	148	22	16	21	0	17	50	0	2	975
32	33	88	45	128	38	36	111	85	106	65	53	81	93	1,757
23	322	43	38	160	97	44	43	8	98	47	28	152	43	1,765
35	81	31	15	106	89	80	21	33	34	25	90	17	178	1,236
63	106	148	8	91	42	69	90	207	59	137	41	134	84	2,444
0	23	9	7	106	48	12	61	32	3	16	16	74	30	1,088
25	8	4	11	4	0	0	0	0	2	0	32	0	0	274
0	7	6	0	1	37	29	0	6	0	1	0	10	15	196
3	0	0	0	0	0	0	0	0	0	24	0	0	0	103
0	3	0	0	0	0	0	0	0	0	0	0	7	0	16
8	19	0	16	0	3	3	3	0	1	0	0	0	3	198
16	11	54	32	32	29	75	31	23	29	77	52	61	201	1,473
1,187 -464	1,794 +143	1,718 +67	1,483 -168	1,937 +286	1,519 -132	1,384 -267	1,734 +83	1,617 -34	1,561 -90	1,826 +175	1,685 +34	1,733 +82	1,526 -125	44,576 1,651

When this result was first obtained, I hoped to find in it a clew to the law of the inversion of the type curve detected in the earth's field, but a persistent study of the possible physical relations of such curves to positive and magnetic fields failed to disclose any rational explanation of the connection along these lines, and this phenomenon is therefore left to stand by itself for what it is worth. It is certainly a remarkable coincidence, if in reality it is nothing more. There may be some reason in the physics of the sun why the spots tend to form along the several meridians, with excess and defect on the same meridian in the opposite hemispheres, due to the so-called positive and negative magnetism, but no definite suggestion is here advanced. Regarding the sidling to the right and left there is more to be said, because, as already shown, the south coronal pole appears to stand a quadrant in advance of the northern, so that the magnetic meridians should be drawn downward and to the right across the disk, causing southern spots to be in advance and northern behind the point where the magnetic meridian crosses the solar equator. This also is stated merely as a suggestion available in a further study of this curious question. Of the main fact there seems, however, to be no doubt, namely, that a distinct tendency exists to form spots more frequently or larger on certain meridians than on others, and that the representative curve conforms very closely to the typical curve of the 26.68-day period.

THE VARIATIONS OF LATITUDE IN CHANDLER'S PERIOD.

The relative numbers, taken year by year, also require a few remarks. They show the sun-spot frequency on the scale adopted above. If we extract from *Jahrbuch der Astronomie u. Geophysick*, III, 1892, p. 14, the relative sun-spot numbers of Wolf, for the years 1830 to 1892, and supplement them with those given in *Terrestrial Magnetism*, Vol. 1, No. 3, p. 150, the annual numbers yield the well-known curve given on chart 30. The second curve of the same is plotted from the numbers of Tables 34 and 35. It shows a little less clearly the tendency to superpose a $2\frac{3}{4}$ -year period, already mentioned in the preceding chapter, upon the 11-year period. The third curve is derived from Chandler's formula for the secular variations of the latitude of the earth's pole of rotation, as deduced from his discussion of the variations of declination of star places, during the past century. The formula is $\varphi - \varphi_0 = -0.10'' \cos (t - 1830) 30^\circ$, and it gives maxima in 1836, 1848, 1860, 1872, 1884, 1896, with minima in 1842, 1854, 1866, 1878, 1890.

I am not in a position to judge how reliable the factor 30° is, upon which the recurrence of the maxima and minima depends. Inasmuch as Chandler's observational data are of greater value since the year 1830, and of less accuracy in the eighteenth century, the evident agreement of the sun-spot curve with the latitude curve for half a

century is suggestive of some physical connection. If the 30° were to be better replaced by 31.5° , then the curves will coincide for an immense length of time; as it is, they will run off and coincide again in 20 periods, 225 years. Now, since the proposed explanation of Chandler's secular 12-year period of latitude variations does not show how this synchronism can occur, it may be remarked that the physical properties of the solar magnetic field developed above are entirely in favor of such a terrestrial effect as the one found in astronomical observations. For if the magnetic field in the neighborhood of the earth increases in strength with the sun-spot period, which is unquestioned, then the earth, being immersed in it, will be subject to proportionally stronger couples, tending to bring the axis of its magnetization parallel to the mean direction of the external field. As this is opposed by the forces producing precession and nutation, we have the resulting swing of the earth's axis of rotation relatively to some nor-

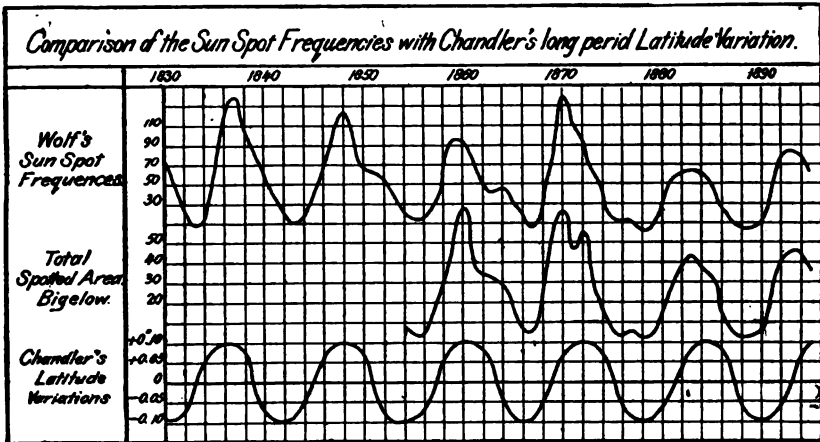


CHART 30.—Comparison of the sun-spot frequencies with Chandler's long-period latitude variation.

mal fixed direction. If the Chandler period can be reduced to agree with the sun-spot period, this conclusion will be decidedly the best explanation of the phenomena. A computation from astronomical data of the force required for this effect may also afford another determination of the strength of the solar magnetic field outside the earth.

THE LAW OF THE INVERSION OF THE NORMAL TYPE CURVE.

The next problem to consider is the law of the phenomenon of inversion of the normal type curve, which has been shown to have an intimate connection with the position of the trace of the sun's axis of rotation upon the plane of the ecliptic. The direct type prevails when the earth is in the quadrants whose centers are parallel to this trace, and the inverse type in the quadrants whose centers are perpendicular to the plane of the sun's axis—the former therefore central March 6

and September 6 at right angles to the nodes of the sun's equator, the latter central June 5 and December 5, upon the line of these nodes. This conclusion depends solely upon the validity of the 26.68-day ephemeris, the correctness of the normal curve, and a careful matching of it with the observations of the terrestrial magnetic and meteorological elements recorded in each period.

The solution is approached by analyzing the lines of force of a distant spherical magnet whose axis coincides with that of the sun's axis of rotation, the positive pole being to the northward of the plane of the ecliptic. An isolated positive magnetic unit mass is assumed as the exploring point, which, if free to move, will traverse the lines of force from the north side to the south side of the ecliptic, and thus reach the earth upon its northern hemisphere. The same unit mass would trace the course of the lines in the earth's magnetic field from the southern into the northern hemisphere—that is, in the opposite direction to the sun's lines. In order to draw the line or tube that leaves the sun and finally embraces the earth at a given instant, or would contain the earth constantly if the rotation of the sun was of the period 365.25 days, we have the formula,

$$N = 2\pi (\frac{1}{3}\pi R^3 I) \frac{\sin^2 \theta}{r};$$

or regarding the moment

$$M = VI = \frac{1}{3}\pi R^3 I = \text{unity},$$

for a type diagram,

$$N = 2\pi \cdot \frac{\sin^2 \theta}{r}.$$

For the determination of the constant N ,

$$\frac{R = \text{radius of the sun}}{r = \text{the distance of the earth}} = \frac{1}{214.4}.$$

Hence, for $R = 1$, $\theta = 90^\circ$ and $r = 214.4$, $N = 0.02936$.

To complete points along the line N :

θ	$\text{Log } \sin^2 \theta.$	$\text{Log } r.$	$r.$
0			
10	18.47934	0.81056	6.5
20	19.06810	1.39932	25.1
30	19.39794	1.72916	53.6
40	19.61614	1.94736	88.6
50	19.76850	2.09972	125.8
60	19.87506	2.20628	160.8
70	19.94598	2.27720	189.3
80	19.98670	2.31792	207.9
90	20.00000	2.33122	214.4

The points plotted from these coordinates (r, θ) in each quadrant produce the curve of chart 32 from the center, O, and this system of magnetic ovals shows the curvature of the lines in space between the sun and the earth. The length of these lines between the sun and the earth is 92,834,000 miles multiplied by $\frac{4}{3}$, or 139,251,000 miles, as can be found by integrating the curve from 0° to 90° , for N, r , given above. The transmission of magnetic energy, therefore, is along a path three-halves the length of that of the linear electro-magnetic radiation for the force affecting the earth. Of course the interplanetary spaces are filled with the same kind of energy, decreasing in intensity from the sun outward in the ratio of the inverse cube of the distance, and it is therefore considerably greater in the neighborhood of the planets Venus and Mercury.

Since the axis of the sun, S, is inclined to the axis of the ecliptic, K, at the angle 7° , and as before indicated the pole of the corona is located at 5° from the sun's poles, the result follows that in the course of the year the earth occupies points along the curve (r, θ) from 0° to about 12° each side of the longest diameter of the ovals. To compute the angles at which these solar lines approach the earth, in extreme positions, we may take for illustration radii making the angles 10° from the diameter. The components of magnetic force emanating from a close doublet are—

$$PA = 2 M \frac{\cos \theta}{r^3} \text{ along the radius.}$$

$$PB = M \frac{\sin \theta}{r^3} \text{ perpendicular to the radius.}$$

PC=resultant force, whose direction is required, being the tangent to the oval at P. (Chart 32.) Constructing a close doublet AB (Chart 31), the demonstration proceeds as there written, following J. J. Thomson, Elements of Electricity and Magnetism.

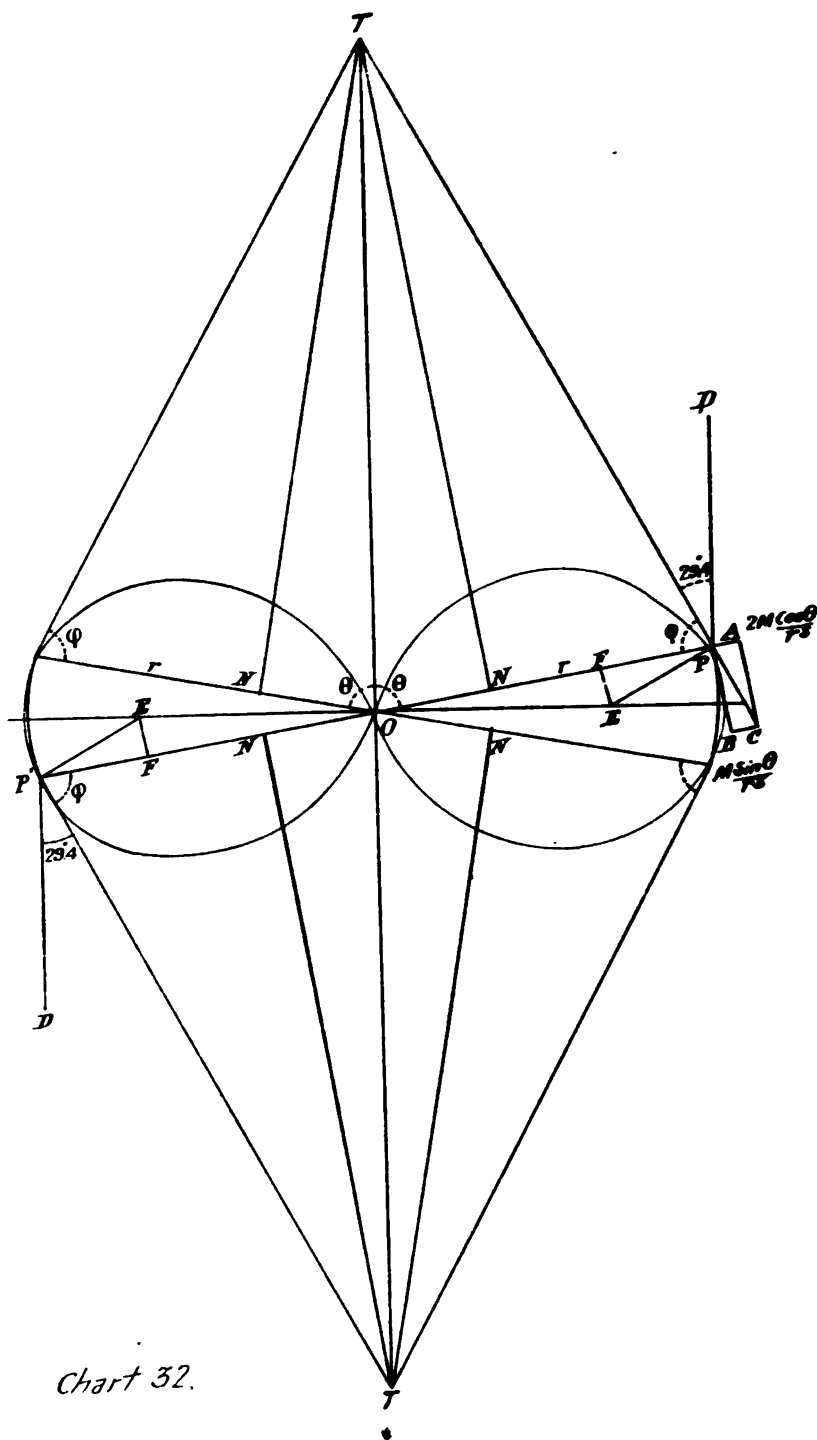


Chart 32.

RESOLUTION OF FORCES IN A DOUBLET.

$$\text{Along AP} = + \frac{e}{r_1^2}.$$

$$\text{Along BP} = - \frac{e}{r_2^2}.$$

$$\begin{aligned} \text{Along OP} &= \frac{e}{r_1^2} \cos \text{APO} - \frac{e}{r_2^2} \cos \text{BPO}. \\ &= \frac{e}{r^2} \left(1 + \frac{2a}{r} \cos \theta \right) - \frac{e}{r^2} \left(1 - \frac{2a}{r} \cos \theta \right). \\ &= 4ae \frac{\cos \theta}{r^3} = 2M \frac{\cos \theta}{r^3} \text{ approximately.} \end{aligned}$$

$$\begin{aligned} \text{Along PD} &= \frac{e}{r_1^2} \sin \text{APO} + \frac{e}{r_2^2} \sin \text{BPO}. \\ &= \frac{e}{r_1^3} a \sin \theta + \frac{e}{r_2^3} a \sin \theta. \\ &= 2ae \sin \theta = M \frac{\sin \theta}{r^3} \text{ approximately.} \end{aligned}$$

$$\cos \text{APO} = \cos \text{BPO} = 1 \text{ for small angle.}$$

$$\sin \text{APO} = \frac{\text{AE}}{\text{AP}} = \frac{a \sin \theta}{r_1}.$$

$$\text{AP} = \text{OP} - \text{AO} \cos \theta.$$

$$r_1 = r - a \cos \theta.$$

$$r_1^2 = r^2 - 2ar \cos \theta + a^2 \cos^2 \theta.$$

$$\frac{1}{r_1^2} = \frac{1}{r^2} + \frac{2a}{r^3} \cos \theta \text{ approximately.}$$

$$\frac{1}{r_2^2} = \frac{1}{r^2} - \frac{2a}{r^3} \cos \theta \text{ approximately.}$$

Then Gauss's theorem becomes (chart 32),

$$\tan \varphi = \tan \text{OPT} = \frac{\text{TN}}{\text{PN}} = \frac{\text{PB}}{\text{PA}} = \frac{M \sin \theta}{r^3} \cdot \frac{r^3}{2M \cos \theta} = \frac{1}{2} \tan \theta = \frac{\text{TN}}{2 \text{ON}}.$$

$$\text{PN} = 2 \text{ON}.$$

$$\text{OP} = 3 \text{ON}.$$

As this relation holds constantly on the curve whose coordinates are r, θ , a graphic construction is effected by taking $\text{ON} = \frac{1}{3} r$, drawing a perpendicular from N upon OT, and joining PT, which is the tangential direction required. Since the angle φ rotates through 180° while θ changes 90° , the curvature of the oval is rapid.

For $\theta = 80^\circ$, $\tan \theta = 5.6713$, $\tan \varphi = 2.8357$, $\varphi = 70^\circ 34' = \text{OPT}$. $\text{OPD} = 100^\circ$, and $\text{TPD} = 29^\circ 26'$. Similarly other angles for assumed values of θ may be found. The direction of the radius of curvature at any point is obtained by drawing from F, where $\text{PF} = \frac{1}{3} \text{PO}$, a perpendicular upon the diameter at E, and connecting PE; then the length of the radius of curvature is found by the usual formula. It is perceived that at the opposite points, PP' , our exploring magnetic mass runs parallel, and therefore the lines of the solar field at these points are directed parallel to each other, making thus an angle of about 30° with the direction, PD, of the axis of polarization.

CHART 32.—Application of Gauss's theorem to the construction of a magnetic oval at the point, $r=208$, $\theta=80^\circ$.

Now consider the actual relations between the sun and the earth. Let K =pole of ecliptic, S =pole of the sun, E =pole of the earth, in the astronomical triangle at the center of the sun on Chart 33. EKS is turned upward through a right angle, about KS , into the plane of the paper for convenience of drawing. The following well-known angular relations exist:

F =angular distance between the sun's equator and the earth's equator.

D =angular distance between the sun's equator and the ecliptic.

$EOK=G$ =angle at O between poles K and E .

$KOS=H$ =angle at O between poles K and S .

$\tan F = \tan \omega \sin \odot$.

$\sin D = \sin I \sin (\odot - N)$.

For F and D , $+$ =south; $-$ =north.

$\tan G = \tan \omega \cos \odot$.

$\tan H = \tan I \cos (\odot - N)$.

For H and G , $+$ =east; $-$ =west.

$I = 7^\circ 15'$.

$N = 74^\circ 0'$.

$\omega = 23^\circ 27'$.

Values of $H G D F$.

Date.	H	G	D	F	Date.	H	G	D	F
	° /	° /	° /	° /		° /	° /	° /	° /
January 1.....	-6 28	4 41	-3 16	-23 4	July 1.....	6 22	-4 8	3 8	23 10
February 1.....	-3 49	16 19	-6 10	-17 45	August 1.....	4 9	-15 20	5 57	18 35
March 1.....	-0 25	22 16	-7 14	-8 10	September 1.....	0 38	-22 3	7 13	8 50
April 1.....	3 22	23 2	-6 26	4 57	October 1.....	-3 0	-23 14	6 37	-3 35
May 1.....	6 5	18 10	-3 57	15 30	November 1.....	-5 58	-18 36	4 9	-15 18
June 1.....	7 14	8 4	-0 23	22 17	December 1.....	-7 14	-8 42	0 35	-22 5

In the course of the revolution of the earth about the sun KS is seen under the varying angle H , whose maximum is $7^\circ 15'$; KE is seen under the varying angle G , whose maximum is $23^\circ 27'$, and SE is seen under the varying angle $(H + G)$, whose maximum is $26^\circ 20'$. Viewed from the earth on June 5 and December 5, $(H + G) = (7^\circ + 8^\circ) = 15^\circ$; and from the earth on September 6 and March 6, $(H + G) = 22^\circ$. On the former dates our sight line is perpendicular to the plane KOS ; on the latter it is in the plane KOS . These are two extreme positions to which our exposition may be limited, other dates being proportionally related to them.

According to our supposition, OS represents the mean position of the axis of the coronal field during one rotation of the sun on its axis, and it will therefore be temporarily taken for the axis of magnetization of the sun. Constructing the magnetic ovals for March 6 and September 6, and conceiving the same system to be rotated about the axis OS , through 90° for the dates June 5 and December 5, the plane of the ovals for these dates is represented on the diagram by the trace OS , and the curvature involving the earth is that of the ovals near the extremity of the diameter. Throughout the motion of the earth in the orbit its mean magnetic axis may be taken to coincide with the axis of rotation, for the mean of the 24-hour components employed in

CHART 33.—Relation of the lines of the magnetic ovals to the earth's axis at four points in the orbit.



Chart 33.



the computation—that is, the average composition of the forces acting on the earth during twenty-four hours—lies in lines always parallel to OE in its true spacial position. The components at the earth may be resolved into KE_1 and EE_1 . The component EE_1 at the earth is expressive of the facts that all magnetic lines are perpendicular to the plane of the ecliptic except in the planes passing through the center of the sun, and that these external lines fall upon the earth primarily at 22° from its axis of rotation. The phenomenon of distortion by a permeable shell is omitted here from consideration; the axis of the undisturbed external field will touch the earth at 22° from the geographical axis and describe a circle about it daily. This may be closely connected originally with the location of the axis of the principle magnetic moment of the earth at about 23° from the poles of rotation and having a period of three thousand one hundred and forty-seven years.¹ Practically, as already shown in a preceding chapter, the magnetic lines are distorted, and they spread out over the earth from the center of the auroral ovals.² For purposes of our subject of inversion this 22° component EE_1 can be laid aside, because it is evidently constant throughout the year, in consequence of the earth carrying its axis stiffly through the magnetic field always parallel to itself; the component E_1K is the variable one to consider.

With the other component E_1K the case is entirely different, since the curvature and position of the ovals now become the leading consideration. As already shown, the September 6 position is above the diameter of the oval on the average 7° , which rises to 12° during the rotation of the coronal field, its pole being 5° from sun's axis. At $\theta=83^\circ$, $\varphi=76^\circ 12'$, and hence MPS (Chart 33)= TPD (Chart 32)= 21° ; for $\theta=80^\circ$, $MPS=30^\circ$. Since $SPE_1=H+G=15^\circ$, we have MPE_1 varying from 6° to 15° , so that the magnetic lines always fall on the earth upon the same side of the plane EOK containing the earth's axis. At March 6 the earth is below the diameter of the sun's magnetic ovals, but precisely the same facts hold true regarding the positive magnetic exploring pole which approaches the earth along the line MP, being parallel to the September line PM.

As the earth passes along its orbit, from March 6 it gradually approaches the diameter of the ovals and reaches it on June 5. The magnetic lines are perpendicular to the radius vector there, since for $\theta=90^\circ$, $\varphi=90^\circ$, but the plane containing the magnetic line is now parallel to SO, which makes the angle $SOE_1=15^\circ$ with the plane of the earth's axis, now, however, on the opposite side of it from the March date. In the same way at December 5 the magnetic field is again parallel to SO; MO for June 5 and December 5 is drawn parallel to SO.

We have thus shown that the only variable component of the solar magnetic field effectively approaches the earth from north to south,

¹ V. Carlheim-Gyllensköld, *L'attraction Magnétique de la Terre*, p. 24.

² Van Bemmelen.

first on one side of the plane of the earth's axis, in March and September, and second on the opposite side, in June and December. The effect is to place the earth as a magnetized sphere in two sets of opposite couples during the course of a year, and we have only to trace out the action of such couple systems of magnetic forces within the earth's field to show that the observed phenomenon of inversion of the curve of typical strength of the solar field from meridian to meridian is a direct consequence of such shifting of the direction of an external field. The case may be summarized by saying that the inverse type is the one due to the magnetic action in the plane of the ovals inclined at an angle SOE_1 to that component of the earth's axis resolved perpendicular to the plane containing the trace of the sun's axis, POS, and the direct type of the effect of the curvature of the ovals themselves in their own planes. The same sequence would be found by turning the arc of the oval about an axis and sliding the point of contact up and down the line of force as required by the astronomical coordinates.

It may be remarked that the fact of the discovery of the direct type in the computation before the inverse type, is due to the somewhat stronger magnetic force prevailing for the couples in March and September; and the fact that the inverse type is rather more firmly developed in the magnetic and the meteorological curves is because the field itself is inclined at a larger effective angle for the couples in June and December. The peculiar penumbra of uncertainty in passing from one quadrant to the other, from the direct to the inverse periods, shown on chart 19, which constituted the great difficulty in detecting the fundamental law, is clearly due to the action of the solar magnetic lines being then very nearly in the plane of the earth's effective axis, and thus producing no steady distortion of the earth's field by the couple. Of course, any irregularity in the solar output, any swaying about of the field in space must show itself in a corresponding irregularity at the earth. The employment of the mean of the 24-hour observations eliminated to a large extent this source of confusion and enabled us to find an approximate normal field during a rotation of the sun on its axis. Abnormally large disturbances occur in consequence of spasmodic outbursts of the sun conveying energy to all the interplanetary spaces and setting up an unusually strong field of magnetic force, which, being impressed upon the earth's field, is measured in the components $H D V$ at the several stations.

Having arrived at the conclusion that an external field of force directed alternately from opposite sides of the axis acts upon the earth's magnetic field, we have to inquire what the effect is in detail upon the lines of the earth's field at all stations of the earth simultaneously. It is not sufficient to consider the mean effect upon the earth as a magnet acted upon by a couple taken as a whole, but the deflections of the lines throughout the medium surrounding the earth must be studied in detail, because our magnetic observations are made at individual points

of such a disturbed medium, and it is the effect of these couples upon the H D V of each station that is required. According to the preceding analysis we have (1) an external field, (2) an induced doublet or equivalent uniformly magnetized sphere whose forces are, if H is parallel to the axis x,

$$\begin{aligned}
 (2) \quad {}^1X_z &= \mp R^3 \frac{\mu-1}{\mu+2} H. & \frac{1}{r^3} \left(1 - \frac{3x^2}{r^2} \right) + H. & \begin{array}{l} \text{Inflected system.} \\ \text{Exflected system.} \end{array} \\
 {}^1Y_z &= \mp R^3 \frac{\mu-1}{\mu+2} H. & \frac{1}{r^3} \left(1 - \frac{3xy}{r^2} \right). & \text{“} \\
 {}^1Z_z &= \mp R^3 \frac{\mu-1}{\mu+2} H. & \frac{1}{r^3} \left(1 - \frac{3xz}{r^2} \right). & \text{“}
 \end{aligned}$$

for points in the external field; the inflected system being applicable to the equatorial portion of the magnetic shell of the earth, and the exflected system to the polar regions; the induction of the doublet being approximately parallel to the axis of the external field, which therefore shifts with the seasons of the year; (3) the permanent internal field of the earth,

$$\begin{aligned}
 (3) \quad X &= -\frac{4}{3} \pi R^3 I \frac{1}{r^3} \left(1 - \frac{3x^2}{r^2} \right) \\
 Y &= +\frac{4}{3} \pi R^3 I \frac{1}{r^3} \left(\frac{3xy}{r^2} \right) \\
 Z &= +\frac{4}{3} \pi R^3 I \frac{1}{r^3} \left(\frac{3xz}{r^2} \right)
 \end{aligned}$$

The formation of formulæ (2), (3) has been already indicated in chapter 3. A further analytic development of the coefficient $R^3 \frac{\mu-1}{\mu+2} H$, occurring under (2) may be added at this place.

If a permeable mass is placed in an external field a doublet is induced of opposite polarity to the direction of the external field. The state of an external field at any instant may be analyzed by superposing upon a normal field another variable field, inducing internal doublets, alternately in opposite directions, according as the actual field is greater or less than the normal field. The observed variations ΔD , ΔI , ΔV in the earth's magnetic field may thus be regarded as the components of a secondary force superposed upon the earth's steady normal field. The case before us supposes no permanent secondary internal magnetization, and is therefore applicable to the earth's shell; the field magnetized in the earth's nucleus remains meanwhile steady, except for its secular variations of long period.

RESOLUTION OF FORCES IN AN INDUCED DOUBLET.

$$QC = AB = -M \frac{\sin \theta}{r^3} = -H \frac{\mu-1}{\mu+2} \frac{R^3}{r^3} \sin \theta$$

$$QD = FE = +2M \frac{\cos \theta}{r^3} = 2H \frac{\mu-1}{\mu+2} \frac{R^3}{r^3} \cos \theta$$

$$GE = BQ = H \sin \theta$$

$$EQ = H \cos \theta$$

$$DS = QL = H_1 \sin \theta$$

$$QD = LS = H_1 \cos \theta$$

$$AQ = QL = H \sin \theta - M \frac{\sin \theta}{R^3} = H_1 \sin \theta. \quad \text{Tangential.}$$

$$FQ = \mu LS = H \cos \theta + 2M \frac{\cos \theta}{R^3} = \mu H_1 \cos \theta. \quad \text{Normal.}$$

$$H - \frac{M}{R^3} = H_1 \quad H + \frac{2M}{R^3} = \mu H_1$$

$$H_1 = \frac{3H}{\mu+2} \quad M = \frac{H(\mu-1)}{\mu+2} R^3$$

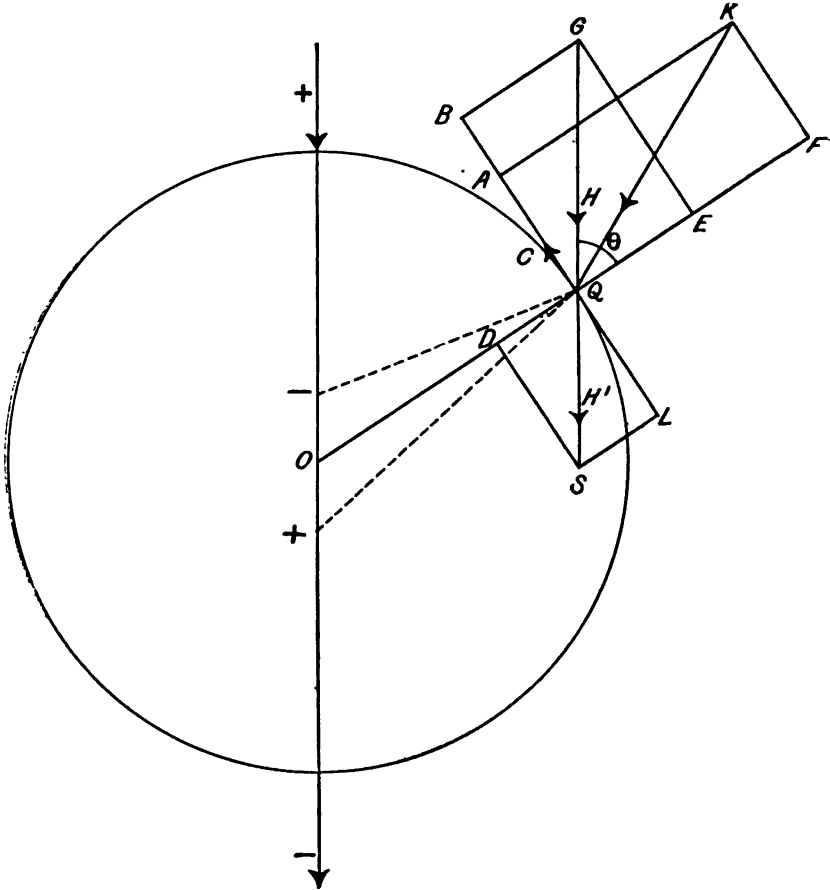


FIGURE 34.—Resolution of forces in an induced doublet.

The external field is deflected to pass through the permeable mass. Pursuing this analysis to all points in the neighborhood of the sphere, also including the deflected case of an impermeable nucleus, we have a distribution of force shown on Chart 8, of which additional details are given on Chart 12.

By means of these formulæ any possible case can be solved in detail, but as our purpose is to explain general ideas, we will pass to some empirical diagrams which show at a glance the deformation of a magnet field when placed in several standard positions within the external field of force.

It may be remarked once more that if an ideal distribution of the earth's magnetization be assumed, such as a uniform internal force parallel to an axis, either the axis of the earth's rotation or the axis of its magnetization, a certain type of normal force must be developed, derived from a potential, to which the observed H. D. V. over the earth correspond. If this same magnetized sphere be placed in an external field the normal field will be permanently changed by the superposition of an induced doublet. In our special case of a central sphere and superincumbent spherical permeable shell the deformation of the normal field will be such as is indicated by the curve of intensity of the impressed field (Chart 11). That, however, should be inverted from the position there given, because the strong impressed external field will make depressions in the resultant field, referred to a simple normal field. The problem of the Gaussian Harmonic Analysis must therefore fully take account of those two fields, and also the induced currents arising from their variations in strength, or from their relative motions in space.

The following typical charts (35 to 39 inclusive) of the lines of force surrounding a magnet, placed at different angles to the horizontal component of the earth's field, were constructed by moving a small exploring magnet compass so as to be constantly tangent to the lines, and tracing out the course of successive lines about a magnet of the following dimensions:

Moment of inertia of the bar,

$$T = \left(\frac{l^2}{12} + \frac{r^2}{4} \right) P \quad \text{cm}^2 \text{gr} = 675.27$$

Magnet moment,

$$ma = M = \pi^2 n^2 \frac{T}{H} S^3 = 1080.$$

where

$l = 11.5$ c. m.

length of magnet.

$r = 0.45$ c. m.

semidiameter.

$P = 61$ grams.

weight.

$n = \frac{11}{60} = 0.18.$

number of half swings per minute.

$$H=0.20.$$

earth's horizontal component.

$$a=\frac{5}{6}l=9.6 \text{ c. m.}$$

the effective distance between the magnet poles.

Hence

$$m=112.4 \text{ C.}^{\frac{2}{3}} \text{ G.}^{\frac{1}{3}} \text{ S}^{-1} \text{ units of pole strength.}$$

$$F=4\pi m=1413.$$

number of lines sent out by the pole.

The external field can also be traced by the usual graphic methods.

The small exploring magnet is itself under a feeble couple from the earth's field, but this can be easily eliminated by making the resulting curve the mean of the branches on opposite sides of the axis. Mark a diameter carefully on the base of the case of the exploring magnet, which was 2.5 cm. long on the one employed; start at any arbitrary point on the large magnet placed exactly parallel to the direction of the earth's field; allow the exploring needle to swing freely, and rotate the marked diameter of the box till it is parallel to the needle; plot in the other end of the diameter, which will be a second point on the same line of force; transfer diameter of the compass to begin at this point, make tangent the needle and diameter, and thus plot a third point. In this way the following diagrams were made, here reproduced on a smaller scale.

The positions of the earth's field and the magnet are marked on each chart. Chart 35 gives the field in its stable position, and shows the lines running from the ends of the magnet off into space, where they are continued into and join upon the lines of the external field. Compare inner portion of Chart 6.

Chart 36 gives the unstable position of the magnet in the field, and indicates that it is so because all the lines of force are closed, returning into the magnet itself. Compare Chart 7. The least movement of the magnet away from this position will release some lines to run into space, and this produces an effective couple, which will turn the magnet, when free to move, into its stable position. If the charts 35, 36 are superposed, we shall see the extreme deformations of the normal field, which were displayed on Chart 8. In the first case, the effect of an external field is to expand all the lines outside the position which they occupied when the magnet was screened from all external fields; in the second case, the lines are all contracted within these normal lines. The effect of an external field directed from magnetic S to N on the magnet is to expand the field as a whole, and that is the same thing as a decrease of the horizontal force everywhere, an increase of the vertical force everywhere, and deflection of the declination, if the lines of the field are not parallel to the external meridians of the magnet. If the external field is directed from N to S along the magnet, opposite effects upon H and V are observed. In the case of the earth and the solar field an increase of the sun's field produces a secondary field relatively to its normal field, which is directed from geographical N to S,

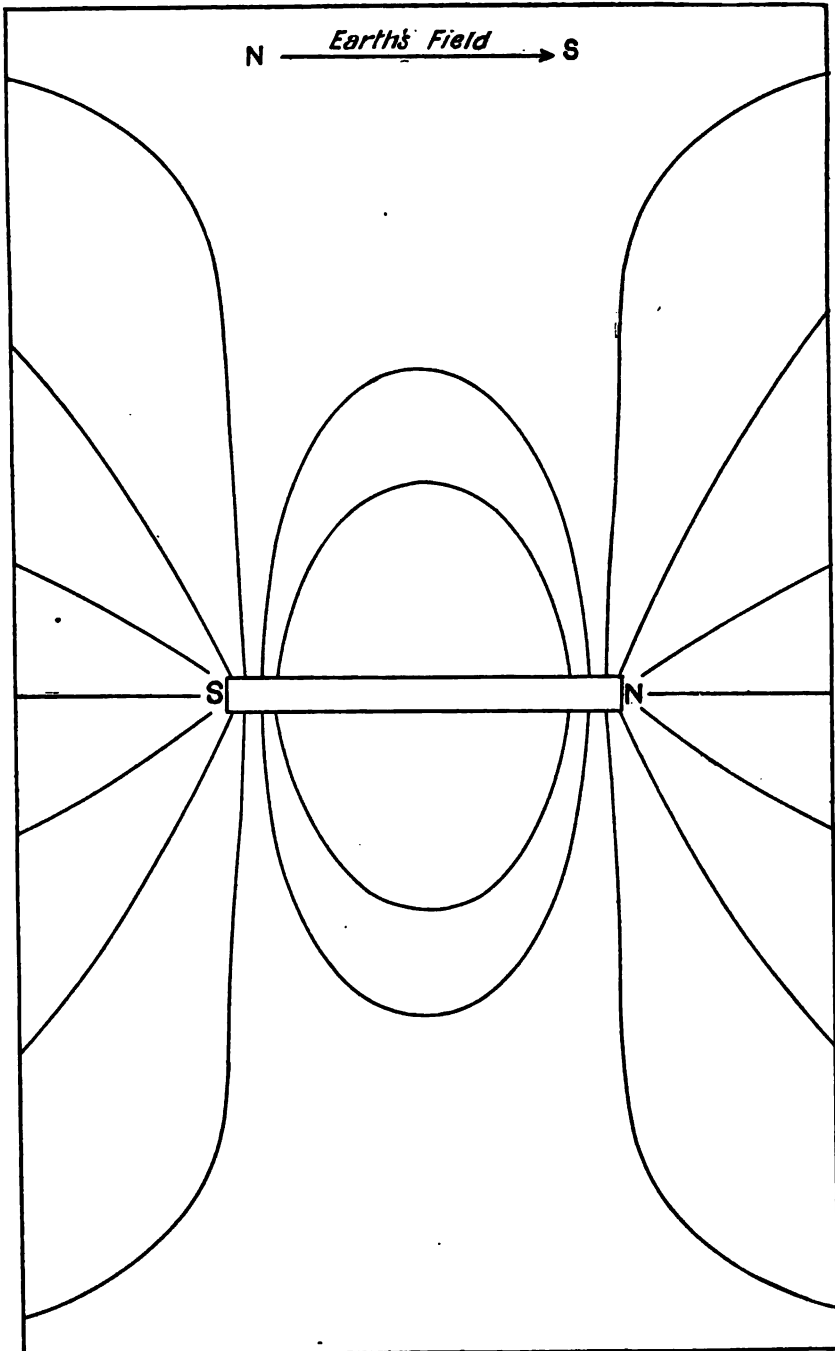


CHART 35.—Magnet in earth's field. Stable position.

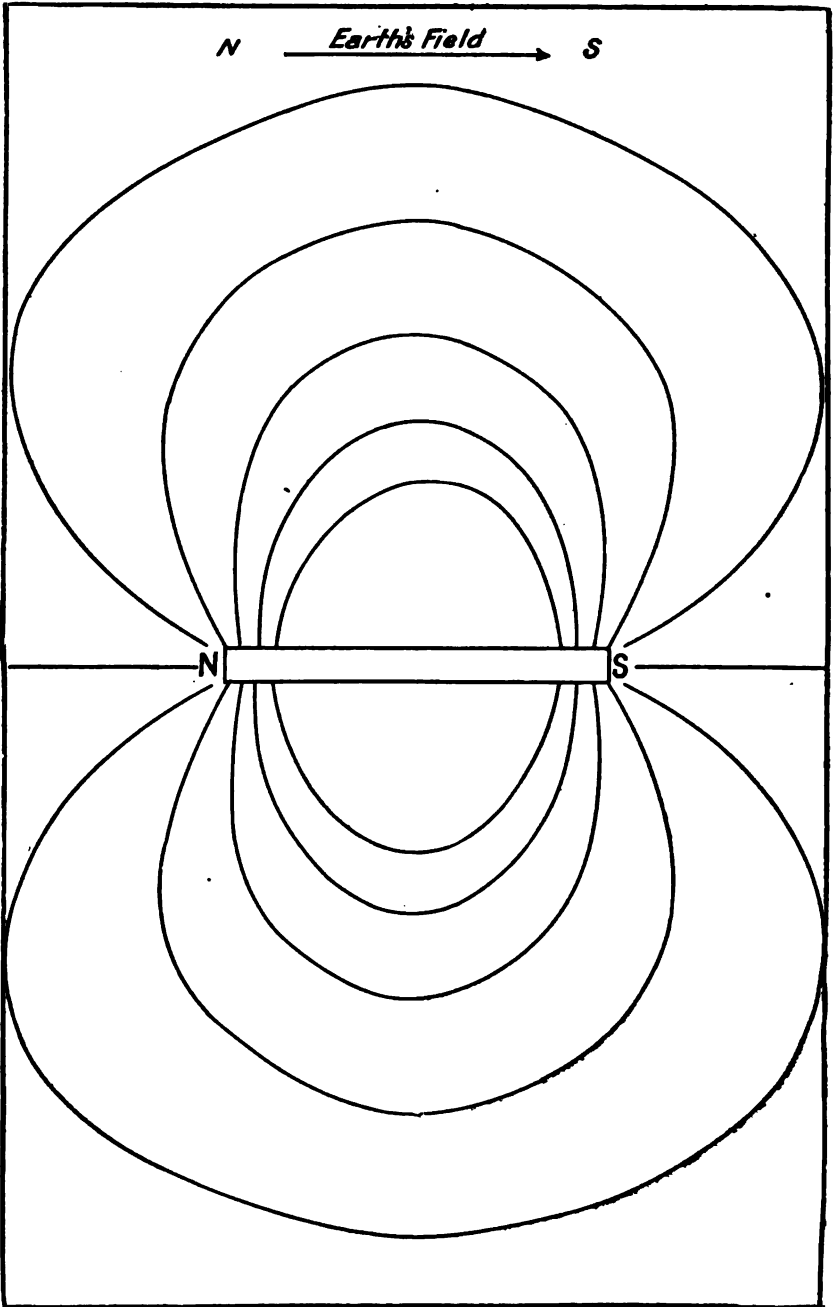


CHART 36.—Magnet in earth's field. Unstable position.

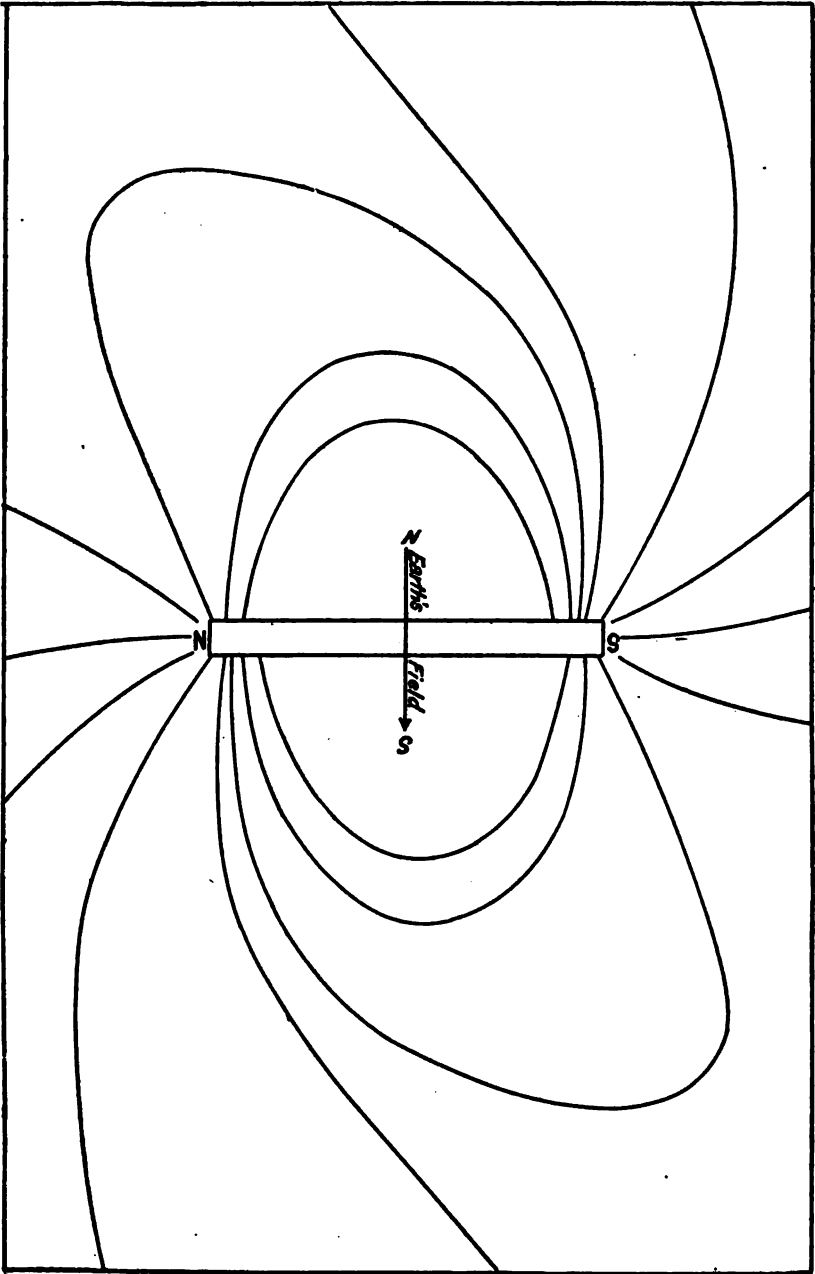


CHART 37.—Magnet lines distorted by earth's field. [N end to the left.]

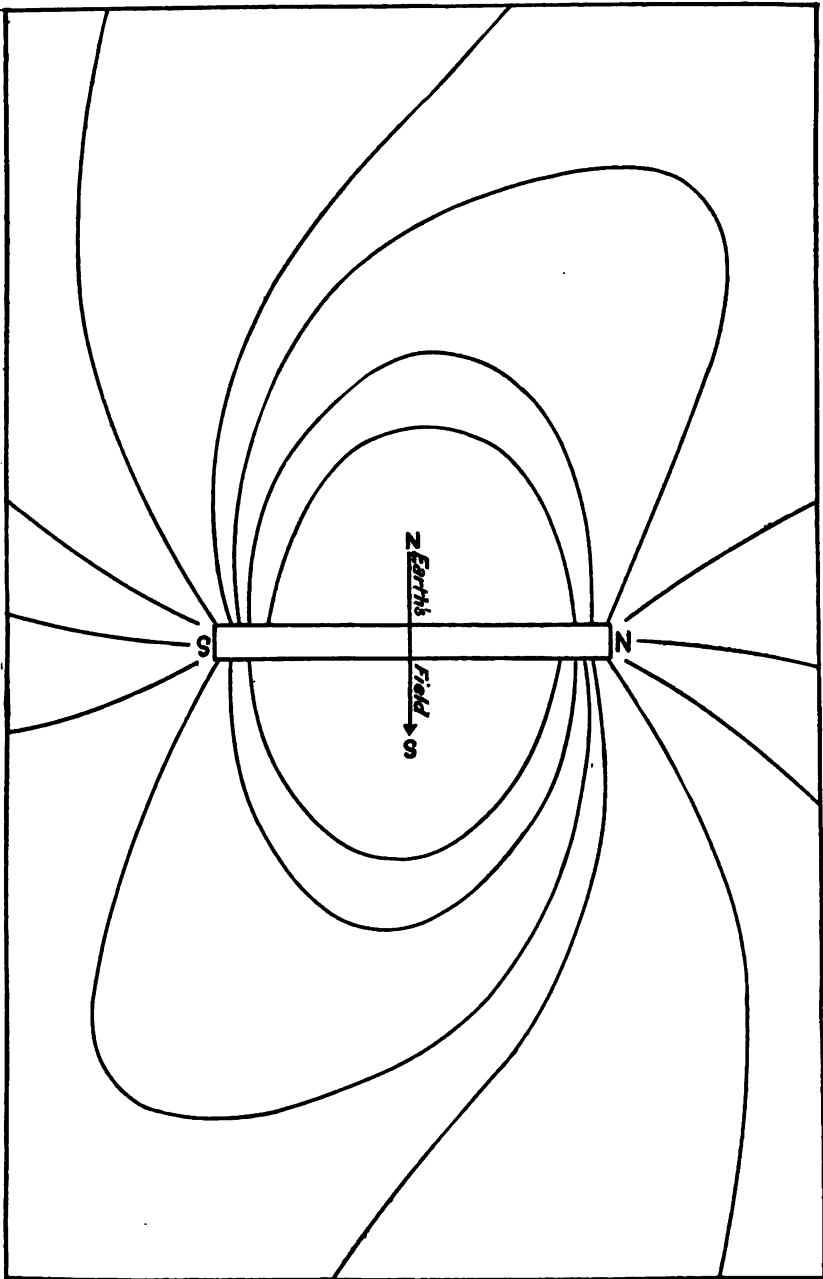


CHART 38.—Magnet lines distorted by earth's field. [N end to the right.]

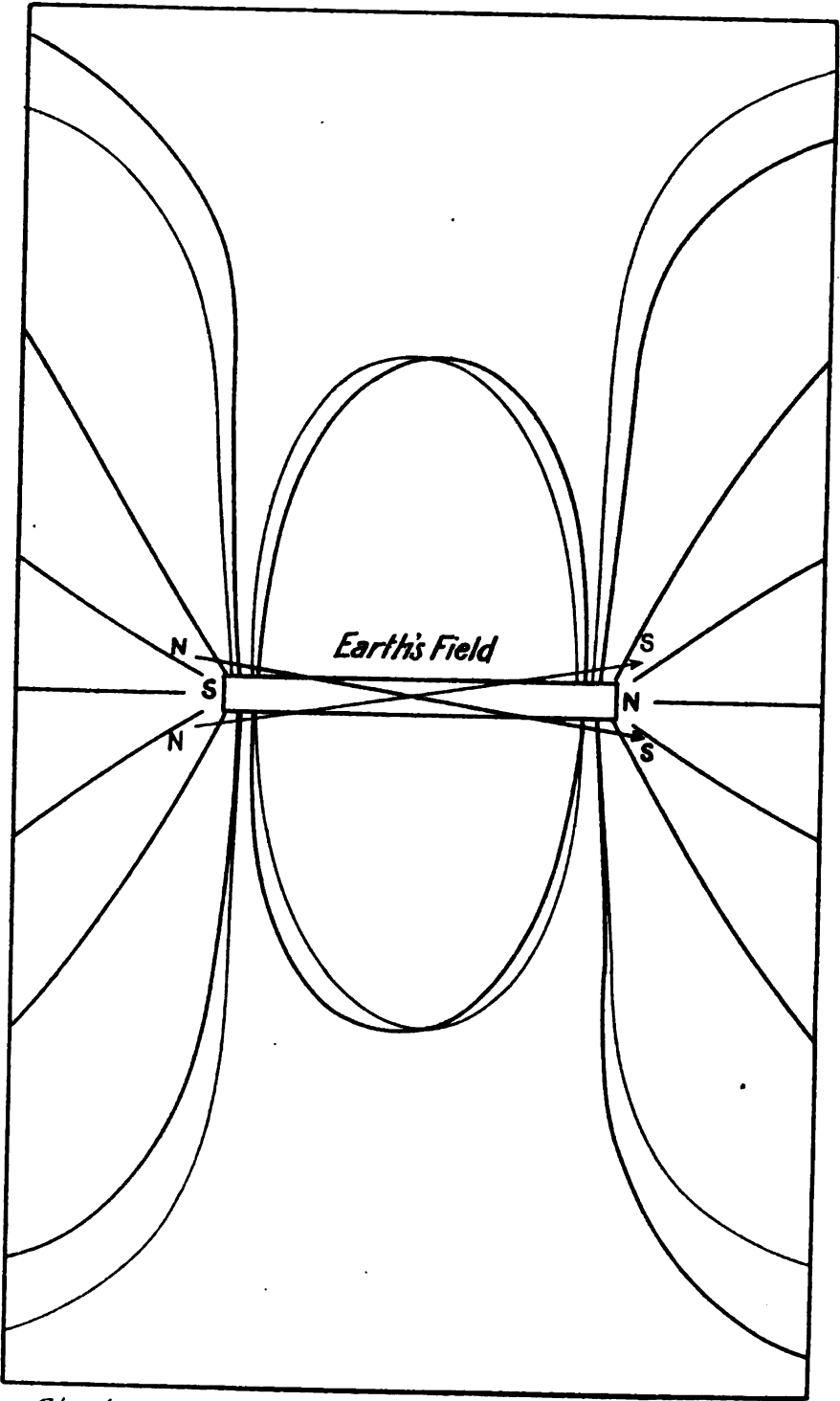


Chart 39.

and increases V , but diminishes H everywhere; a falling off of the solar field below its normal value produces just the opposite effect. The variable line of force traced out from day to day by means of the continuous photographic records in $H. D. V.$, simply represents a secondary field directed from S to N or N to S , respectively, at different moments, according as $H. D. V.$ at the instant observed are less or greater than the normal. The oscillations of the field, in waves, in irregular small vibrations or in perturbations, are thus observed as the simultaneous variations in $H. D. V.$ over the entire earth. A decrease of H . is an increase of external force; an increase of V is an increase of the external field, and must always be so construed. As already mentioned, the great disturbances, having persistent durations of twenty-four hours or more, are observed to be always directed from the northward to the southward side of the ecliptic, and they occur simultaneously at all terrestrial stations. There is no other known cause of such a phenomenon capable of producing this remarkable result. Certainly no local meteorological conditions, and no rotation of the earth as a body, in a hypothetical medium of conducting capacity can account for these peculiar variations, unless the entire atmosphere of the earth, or unless the earth as a mass, has the variable motions corresponding to the observed vibrations of the needle taken from day to day. If, on the other hand, the magnetization of the sun is perturbed irregularly or periodically, then all the observed terrestrial phenomena follow in harmonious sequence.

Starting now from the unstable position of our magnet chart 36, let it swing half-way about, to right and left, till the axis of the magnet makes 90° with the external field. The instructive charts 37, 38 show the distortion of the medium, when the couples are in the positions of maximum power. The impulse to swing is in such a direction as to bring the N of the magnet to S of field, its stable position, as quickly as possible. A portion of the lines are open on opposite sides and drawing, the remainder are closed and pushing, thus distorting in two ways the normal forms of the curves. An opposite turn of 90° will bring the lines into the position of chart 38. When a magnet swings about an axis, its lines are playing through the rapidly varying curves of charts 37, 35, 38, if free to act in their own way; the magnet field may be forced through the forms 37, 36, 38 in succession.

Finally, when near the point of the stable equilibrium, a similar though smaller distortion of the curves takes place, even for slight displacements of the axis.

Chart 39 shows the two positions of the field when its axis is 10° on each side of the axis of the magnet; the undisturbed magnet lines may be drawn through their mean position. This is the practical case of the earth, as before explained, when the direct or inverse types respectively prevail. During the periods of direct type a left-handed couple prevails; and during the periods of inverse type a right-handed couple

CHART 39.—Magnet lines distorted by two couples. [Angle= 10° degrees.]

prevails. The important deduction is that for the same external field the horizontal force of the earth's field is changed in one direction under one couple, and in the opposite direction for the other couple, when measured at any station as compared with the normal field at that place. The phenomenon of inversion is therefore an effect within the earth's field, of the presenting its lines to the direction of an impressed external field from the opposite sides, these couples being generated by the combined aspects of the axes of the earth and sun, together with the peculiar shape of the solar magnetic ovals. The typical curves of chart 8, derived from the observations, therefore find their necessary explanation in these circumstances, and carry with them the proof of the existence of a direct action of the solar magnetic field. To apply all these conditions to the solution of the force observed at any station at a given instant of time is possible, but very complex. Auxiliary tabulations of disturbances, like the terms of an orbit under perturbations, can be constructed to facilitate such a work, and it will become the province of the science of terrestrial magnetism to do so sometime. We may perceive that the Gaussian hypothesis of referring all these forces to an internal potential field of heterogeneous magnetization was imperfect. For the study of the secular variation, all these external terms must be eliminated before the Harmonic Analysis is applied to interpolations on the forces derived from an internal field. To recapitulate, we have, (1) the field from the earth's nucleus of only approximately known distribution; (2) the secondary distribution derived from the electro-magnetic field, varying only with the change of the axis of that field in latitude, including its couples; (3) the secondary distribution derived from the polar magnetic field, varying with the strength of the output from the sun, including its couples and the phenomenon of inversion. The rotation of the earth on its axis enabled us to eliminate the electromagnetic field, and also the local terms in the polar magnetic field, from the external couples; the rotation of the sun on its axis developed the normal type curve of relative intensity; the revolution of the earth in its orbit produced the inversion of the type curve, by the very peculiar conditions involved in the formation of the two systems of couples.

ELEMENTS OF THE SUN AND EARTH AS MAGNETS.

It may be convenient to have for reference the main features of the sun and earth as static magnets, derived in the case of the earth from $I=0.079$ C. G. S., and in the case of the sun from $H=0.00035$ C. G. S. at the distance of the earth. Logarithms are given in the last column.

TABLE 36.—*Magnetic elements of the earth in the C. G. S. system.*

R	Radius of earth	6.37×10^8	8.80414
R^2		4.058×10^{17}	17.60628
R^3		2.5848×10^{26}	26.41242
$\frac{4}{3}\pi$		4.18879	0.62209
I	Magnetization	0.079	8.89763—10
$V = \frac{4}{3}\pi R^3$	Volume of earth	1.083×10^{27}	27.03451
$M = VI. = -F_1 R^2$	Moment	8.55×10^{25}	25.93214
$-F_1 = +\frac{VI}{R^3} = +\frac{4}{3}\pi I$	Interior force	0.33692	9.51972—10
$\Omega_1 = -F_1 r \cos \theta$	Interior potential	$0.33092 r \cos \theta$	
$\Omega_e = -F_1 R^2 \frac{\cos \theta}{r^2}$	Exterior potential	$8.55 \times 10^{25} \frac{\cos \theta}{r^2}$	
$X_e = +F_1 R^2 \frac{(1-3 \cos^2 \theta)}{r^3}$	Exterior x -component (polar)	$8.55 \times 10^{25} \frac{(1-3 \cos^2 \theta)}{r^3}$	
$Y_e = -F_1 R^2 \frac{3 \sin \theta \cos \theta}{r^3}$	Exterior y -component	$8.55 \times 10^{25} \frac{3 \sin \theta \cos \theta}{r^3}$	
$F_n = -2F_1 R^2 \frac{\cos \theta}{r^3}$	Exterior normal component	$17.10 \times 10^{25} \frac{\cos \theta}{r^3}$	
$F_t = -F_1 R^2 \frac{\sin \theta}{r^3}$	Exterior tangential component	$8.55 \times 10^{25} \frac{\sin \theta}{r^3}$	
$F_e = -F_1 R^2 \frac{(1+3 \cos^2 \theta)}{r^3}$	Total exterior force	$8.55 \times 10^{25} \frac{(1+3 \cos^2 \theta)}{r^3}$	
$M = -\frac{4}{3}\pi F_1 R^2$	Mass	1.7904×10^{17}	17.25294
$Q = -3\pi R^2 F_1$	Flow of force	1.266×10^{18}	18.10239
$N = -2\pi F_1 R^2 \frac{\sin^2 \theta}{r}$	Line of force	$5.87 \times 10^{25} \frac{\sin^2 \theta}{r}$	25.73032
$\Omega = -F_1 R^2 \frac{\cos \theta}{r^2}$	Equipotential surface	$8.55 \times 10^{25} \frac{\cos \theta}{r^2}$	

TABLE 37.—*Magnetic elements of the sun (C. G. S.).*

R	6.968×10^{10} (433,000 miles)	10.84314
R^2	4.856×10^{21}	21.68628
R^3	3.384×10^{32}	32.52942
$\frac{4}{3}\pi$	4.18879	0.62209
I	824 from $\Delta H = .00035$	2.91593
V	1.417×10^{33}	33.15151
M	1.168×10^{36}	36.06744
$-F_1$	3451.62	3.53802
Ω_1	$3451.62 r \cos \theta$	
Ω_e	$1.168 \times 10^{36} \frac{\cos \theta}{r^2}$	
X_e	$1.168 \times 10^{36} \frac{(1-3 \cos^2 \theta)}{r^3}$	
Y_e	$1.168 \times 10^{36} \frac{3 \sin \theta \cos \theta}{r^3}$	
F_n	$2.336 \times 10^{36} \frac{\cos \theta}{r^3}$	
F_t	$1.168 \times 10^{36} \frac{\sin \theta}{r^3}$	
F_e	$1.168 \times 10^{36} \frac{(1+3 \cos^2 \theta)}{r^3}$	
m	2.235×10^{38}	25.34924
Q	1.380×10^{38}	26.19857
N	$7.339 \times 10^{38} \frac{\sin^2 \theta}{r}$	36.86502
Ω	$1.168 \times 10^{36} \frac{\cos \theta}{r^2}$	
Q_s / Q_R	1.2479×10^2	8.09618

TWO TYPES OF RADIATION.

We will now make some remarks upon the subject of radiation. From the beginning of my research I have had very definite ideas about the probable outcome of the solar-terrestrial problem, and have therefore adopted some terms that may not have been accepted by students generally in the meaning intended. Radiation can be defined as the transmission of energy from its source through the medium separating it from another body by merely transient disturbances of the medium at the intervening points. Radiation may be of many types. Two kinds alone concern this problem.

Adopting Heaviside's equations and notation, we have:

(1) The electromagnetic radiation from the sun:

$$W = v(U + T) = V \frac{(E - e_0)(H - h_0)}{4\pi}.$$

Its translational force or pressure is:

$$F = V\dot{D}B + V\dot{D}\dot{B} = \frac{d}{dt} VDB = \frac{1}{v^2} \frac{d}{dt} VEH = \frac{1}{v^2} \frac{dW}{dt}.$$

The flux of energy is at right angles to the plane containing the electric force and the magnetic induction. The pressure per square centimeter is inversely proportional to the square of the velocity of propagation and to the time rate of change in the energy flux. The rays of propagation are the radii of the expanding spherical waves of electro-magnetic induction, and the length of path to the earth is about 92,800,000 miles.

(2) The polar magnetic radiation from the sun is of an entirely different nature, and is primarily the transient transmissions of the energy required to change a polar magnetic field of a certain strength to similar field of a different strength. The length of path to the earth is about 135,000,000 miles. As regards such a polar field, it is probably a very misleading conception to ever regard it as static, except in some of its effects. We may as well consider the electro-magnetic field static, because it exerts a steady pressure, but we have fortunately learned to analyze it as made up of immensely rapid vibrations, transmitting energy in wave motions. In a similar way the lines of force surrounding a common magnet are not at rest, but probably consist of vortex tubes, namely, electric currents rotating about the axis of the line of magnetic force with enormous rapidity. I take pleasure in referring to a careful graphical analysis of such a state of the medium in "Magnetische Kraftfelder," H. Ebert, Leipsig, 1896, which illustrates the views mentioned in this connection. The interaction of such vortex tubes affords a mechanical analogue which conforms very closely indeed to the observed physical effects, even if it does not represent the true state of the medium. Now the case of propagation of energy when the magnetic field is varying comes before us. Suppose

a soft iron bar surrounded by a spool of insulated wire, without current at first, lies within an ether medium in a quiescent state; by the action of the electric current, when suddenly impressed, the surrounding medium is set into vortical rotation by the transmission of lines of magnetic force from the iron bar. I can think of no truer word to describe this changing state of the medium than magnetic radiation of energy through it. This field may acquire a steady state, but it is essentially dynamic and not static. The word static in electro-magnetism is so far misleading that it ought to be abandoned, because it means only the steady state of an intrinsically dynamic field. In the same sense, though the sun may be said to maintain a steady magnetic field for short intervals, it is so far restless as to be practically transmitting energy incessantly in passing from one state of intensity to another. This transmission appears to be spasmodic, in large and small disturbances, and if Eschenhagen's observations of minute waves in the magnetic field can not be explained by pulsations derived from terrestrial sources, then likewise in small, quite rapid wave-like vibrations, which come very close to being a true periodic radiation. It must be said that the analysis of a polar field with a positive and negative pole is merely a convenience, and that both poles are probably sources and sinks simultaneously, though the positive is the source and the negative a sink only to the positive isolated pole upon which our analysis has been founded. This polar transient system may be examined more specifically, as it is less commonly understood. The following equations are rearranged from Heaviside's papers:

HEAVISIDE'S NOTATION.

Electricity.

- c** Electric permittivity. $D = \frac{cE}{4\pi}$.
k Electric conductivity. $C = kE$.
E Force of field. $E_1 = (E - e_1)$.
e Motional force. $e = VqE$.
e₀ Intrinsic force.
E Electric force.
D Displacement.
C Conduction current.
J True electric current $= C + \dot{D} + \rho u$.
 ρ Electrification. $\rho = \text{div } D$.
u Velocity.
Q₁ Joulean waste. $Q_1 = kE^2 = EC$.
U Energy stored. $U = \frac{1}{2}ED = \frac{1}{2}cE^2$.
F Polar force.

Magnetism.

- μ** Magnetic inductivity. $B = \mu H$.
g Magnetic conductivity (fictitious).
H₁ Force of field. $H_1 = (H - h_0)$.
h Motional force. $h = VDq$.
h₀ Intrinsic force.
H Magnetic force.
B Induction.
K Conduction current (fictitious).
G True magnetic current $= [K] + B + [\sigma w]$.
 σ Magnetification. $\sigma = \text{div } B$ (fictitious).
w Velocity.
Q₂ Joulean waste (fictitious).
T Energy stored. $T = \frac{1}{2} \frac{HB}{4\pi} = \frac{1}{2} \frac{\mu H^2}{4\pi}$.
 Ω Magnetic potential.

FUNDAMENTAL EQUATIONS.

$$1. \text{curl } (H - h) = 4\pi J = 4\pi(C + \dot{D}) = 4\pi kE + c\dot{E}.$$

$$2. -\text{curl } (E - e) = 4\pi G = 4\pi \left(K + \frac{B}{4\pi} \right) = 4\pi gH + \mu \dot{H}.$$

Multiply the first by $(e - E)$, the second by $(h - H)$, and add,

$$3. eJ + hG = EJ + HG + \left[\frac{(H - h) \text{curl } (E - e)}{4\pi} - \frac{(E - e) \text{curl } (H - h)}{4\pi} \right]$$

$$4. eJ + hG = Q + \dot{U} + \dot{T} + \text{div } \frac{V}{4\pi} (E - e)(H - h) = Q + \dot{U} + \dot{T} + \text{div } W.$$

Eliminate $\mathbf{H}$ and $\mathbf{E}$ successively in (1), (2).

$$5. \text{curl } \frac{1}{\mu} \text{curl } (\mathbf{E} - \mathbf{e}) + \text{curl } \mathbf{h} + 4\pi \mathbf{k} \dot{\mathbf{E}} + \mathbf{c} \ddot{\mathbf{E}} = 0$$

$$6. \text{curl } \frac{1}{\mathbf{c}} \text{curl } (\mathbf{H} - \mathbf{h}) - \text{curl } \dot{\mathbf{e}} + 4\pi \mathbf{g} \dot{\mathbf{H}} + \mu \ddot{\mathbf{H}} = 0$$

For $\mathbf{e} = 0$, $\mathbf{h} = 0$, and $\mathbf{g} = 0$.

$$\left. \begin{aligned} 7. \text{curl } \frac{1}{\mu} \text{curl } \mathbf{E} + 4\pi \mathbf{k} \frac{d\mathbf{E}}{dt} + \mathbf{c} \frac{d^2\mathbf{E}}{dt^2} &= 0 \\ 8. \text{curl } \frac{1}{\mathbf{c}} \text{curl } \mathbf{H} + \mu \frac{d^2\mathbf{H}}{dt^2} &= 0 \end{aligned} \right\} \text{No impressed force in space.}$$

For $\mathbf{c} = 0$.

$$\left. \begin{aligned} 9. \text{curl } \frac{1}{\mu} \text{curl } \mathbf{E} + 4\pi \mathbf{k} \frac{d\mathbf{E}}{dt} &= 0 \\ 10. \text{curl } \frac{1}{\mathbf{k}} \text{curl } \mathbf{H} + 4\pi \mu \frac{d\mathbf{H}}{dt} &= 0 \end{aligned} \right\} \text{Diffusion in metals of } \mathbf{E} \text{ and } \mathbf{H}.$$

For $\mathbf{k} = 0$.

$$\left. \begin{aligned} 11. \text{curl } \frac{1}{\mu} \text{curl } \mathbf{E} + \mathbf{c} \frac{d^2\mathbf{E}}{dt^2} &= 0 \\ 12. \text{curl } \frac{1}{\mathbf{c}} \text{curl } \mathbf{H} + \mu \frac{d^2\mathbf{H}}{dt^2} &= 0 \end{aligned} \right\} \text{Wave propagation in gases of } \mathbf{E} \text{ and } \mathbf{H}.$$

MAGNETIZATION.

Intrinsic magnetization $= 4\pi \mathbf{I}_1 = \mu \mathbf{h}$.

Induced magnetization $= 4\pi \mathbf{I}_2 = 4\pi \mathbf{k} \mathbf{F}$.

$$\begin{aligned} \text{Total induction} = \mathbf{B} &= \mathbf{F} + 4\pi \mathbf{I}_1 + 4\pi \mathbf{I}_2 \\ &= \mathbf{F} + \mu \mathbf{h} + 4\pi \mathbf{k} \mathbf{F} \\ &= \mathbf{F} (1 + 4\pi \mathbf{k}) + \mu \mathbf{h} \\ &= \mu (\mathbf{F} + \mathbf{h}) = \mu \mathbf{H}. \end{aligned}$$

The actual $\mathbf{H} = \mathbf{h}$ (impressed) + $\mathbf{F}$ (polar) + $\mathbf{F}_1$ (current induced).

Some relations between circuital and polar forces.

ELECTRIC CONDUCTOR.

$$\mathbf{E}_1 = \mathbf{e}_1 + \mathbf{F}_1 \quad \mathbf{F}_1 = -\nabla P_1 \quad \mathbf{C} = \mathbf{k} \mathbf{E}_1 \quad \text{div } \mathbf{C} = 0 \quad \text{curl } (\mathbf{e}_1 - \mathbf{E}_1) = 0 \quad \rho_1 = -\text{div } \mathbf{e}_1$$

DIELECTRIC.

$$\mathbf{E}_2 = \mathbf{e}_2 + \mathbf{F}_2 \quad \mathbf{F}_2 = -\nabla P_2 \quad \mathbf{D} = \frac{\mathbf{c}}{4\pi} \mathbf{E}_2 \quad \text{div } \mathbf{D} = 0 \quad \text{curl } (\mathbf{e}_2 - \mathbf{E}_2) = 0 \quad \rho_2 = -\text{div } \mathbf{e}_2 \frac{\mathbf{c}_2}{4\pi}$$

MAGNETIC CONDUCTOR.

$$\mathbf{H} = \mathbf{h} + \mathbf{F}_3 \quad \mathbf{F}_3 = -\nabla P_3 \quad \mathbf{B} = \mu \mathbf{H} \quad \text{div } \mathbf{B} = 0 \quad -\text{curl } (\mathbf{h} - \mathbf{H}) = 0 \quad \sigma = -\text{div } \mu \frac{\mathbf{h}}{4\pi}$$

CASES.

1. Curl $(\mathbf{H} - \mathbf{h}) = 0$, no current.

$\mathbf{F} = -\nabla \Omega$, polar magnetic field; and $\text{curl } \mathbf{F} = 0$.

$$\int \text{curl } (\mathbf{H} - \mathbf{h}) = \mathbf{F} = -\nabla \Omega; \mathbf{H} = \mathbf{h} + \mathbf{F}.$$

$$2. \text{div } \mathbf{G} = 0. \text{div } \mathbf{B} = 0. \int \text{div } \mathbf{B} = \text{div } \mathbf{B} = \text{div } \mu \mathbf{H} = 0.$$

3. Conditions: $\text{curl } (\mathbf{H} - \mathbf{h}) = 0. \text{div } \mu \mathbf{H} = 0$.

Given μ and $\mathbf{h}$ to find $\mathbf{H}$, the actual magnetic force.

$$\text{div } \mu (\mathbf{h} + \mathbf{F}) = 0. \text{curl } \mathbf{F} = 0. \text{div } \mu \mathbf{F} = -\text{div } \mu \mathbf{h}.$$

I. Curl $\mathbf{h} = 0. \text{curl } \mathbf{H} = 0. \text{div } \mu \mathbf{H} = 0. \mathbf{H} = 0$ and $\mathbf{B} = 0$.

If the impressed force be wholly polar there is no induction.

II. $\text{div } \mu \mathbf{h} = 0. \text{div } \mu \mathbf{F} = 0. \text{curl } \mathbf{F} = 0. \mathbf{F} = 0. \mathbf{H} = \mathbf{h}. \mathbf{B} = \mu \mathbf{h}.$

If the impressed force be wholly circuital there is full induction, and no polar force.

This shows that during transient adjustments of a magnetic field from one strength to another there are transient electric and magnetic currents.

TRANSFORMATION OF WORK INTO ENERGY AND HEAT.

Conductor, $Q = \sum \mathbf{E}_1 k \mathbf{E} = \sum \mathbf{e}_1 k \mathbf{E}_1 = \sum \mathbf{e}_1 k \mathbf{e}_1 - \sum \mathbf{F}_1 k \mathbf{F}_1 = \sum \mathbf{e}_1 k \mathbf{e}_1 - \sum \mathbf{F}_1 \rho_1 = \sum \mathbf{E}_1 C = \sum \frac{1}{2} \mathbf{H}_1 G_1.$

Dielectric, $8\pi U = \sum \mathbf{E}_2 c \mathbf{E}_2 = \sum \mathbf{e}_2 c \mathbf{E}_2 = \sum \mathbf{e}_2 c \mathbf{e}_2 - \sum \mathbf{F}_2 c \mathbf{F}_2 = \sum \mathbf{e}_2 c \mathbf{e}_2 - \sum \mathbf{F}_2 \rho_2 = \sum \frac{1}{2} \mathbf{E}_2 D = \sum \frac{1}{2} ZG.$

Magnetic medium, $8\mu T = \sum \mathbf{E}_3 c \mathbf{E}_3 = \sum h \mu \mathbf{H} = \sum h \mu h - \sum \mathbf{F}_3 \mu \mathbf{F}_3 = \sum h \mu h - \sum \frac{1}{2} \Omega \sigma = \sum \frac{1}{2} \frac{HB}{4\pi} = \sum \frac{1}{2} AJ.$

Q = the work wasted in conductors as heat.

U = the electric energy stored in potential form in the dielectric.

T = the magnetic energy stored in kinetic form in the magnetic medium.

Proof of the last form.

Circuital displacement in a dielectric from electro-magnetic induction.

$$\text{div } c\mathbf{E} = 0. \quad -\text{curl } \mathbf{Z} = c\mathbf{E} = 4\pi D. \quad \text{curl } \mathbf{H} = c\dot{\mathbf{E}} = 4\pi J.$$

$$\text{div } \mathbf{B} = 0. \quad \text{curl } \mathbf{A} = \mu \mathbf{H} = \mathbf{B}. \quad -\text{curl } \mathbf{E} = \mu \dot{\mathbf{H}} = 4\pi G = \text{curl } \frac{1}{c} \text{curl } \mathbf{Z}$$

$$U = \sum \frac{1}{2} \mathbf{E} D = \sum \frac{1}{2} \frac{4\pi D}{\text{curl}} \frac{\text{curl } \mathbf{E}}{4\pi} = \sum \frac{1}{2} ZG. \quad \text{Since, } \mathbf{Z} = -\frac{4\pi D}{\text{curl}}, G = -\frac{\text{curl } \mathbf{E}}{4\pi}.$$

$$T = \sum \frac{1}{2} \frac{HB}{4\pi} = \sum \frac{1}{2} \frac{\mathbf{B}}{\text{curl}} \frac{\text{curl } \mathbf{H}}{4\pi} = \sum \frac{1}{2} AJ. \quad \text{Since, } \mathbf{A} = \frac{\mathbf{B}}{\text{curl}}, J = \frac{\text{curl } \mathbf{H}}{4\pi}.$$

Transient to final state.

Transient state $-\text{curl } (\mathbf{E} - \mathbf{e}) = 4\pi G. \quad \mathbf{E}_0 = \mathbf{e} + \mathbf{F}_0 = \mathbf{e} - \nabla P \text{ (Final).}$

Final state $-\text{curl } (\mathbf{E}_0 - \mathbf{e}) = 0. \quad \mathbf{F} = \mathbf{F}_0, \quad G = J_2, \quad J = C + D.$

$$\sum \mathbf{e} J = \sum \mathbf{e} J + \sum \mathbf{F}_0 J = \sum \mathbf{E}_0 J = \sum \mathbf{E}_0 C + \sum \mathbf{E}_0 D = \sum \mathbf{E}_0 k \mathbf{E} + \sum \mathbf{E}_0 D = \sum C_0 \mathbf{E} + \sum \mathbf{E}_0 D.$$

$$\sum C_0 \mathbf{E} = \sum \frac{C_0}{\text{curl}} \text{curl } \mathbf{E} = \sum \frac{H_0}{4\pi} (\text{curl } \mathbf{e} - 4\pi G) = \sum H_0 \left(\frac{\text{curl } \mathbf{e}}{4\pi} - G \right) =$$

$$\sum \mathbf{e} \frac{\text{curl } H_0}{4\pi} - \sum H_0 G = \sum C_0 \mathbf{e} - \sum H_0 G.$$

$$\text{At each instant, } \sum \mathbf{e} J = \sum C_0 \mathbf{e} + \sum \mathbf{E}_0 D - \sum H_0 G.$$

$$\text{The time integral, } \sum \mathbf{e} \int J dt = \sum C_0 \mathbf{e} t + \sum \mathbf{E}_0 D_0 - \sum \frac{H_0 B_0}{4\pi} = \text{final state.}$$

$$\text{The work done} = \sum \mathbf{e} \int J dt = \sum C_0 \mathbf{e} t + 2U - 2T.$$

Proof of the last steps.

Work done by actual forces=

$$\sum \int \mathbf{H} G dt = \sum \int \frac{\mathbf{H} \mu \dot{\mathbf{H}}}{4\pi} dt = \sum \int dt \left(\frac{\mathbf{H} \mu \mathbf{H}}{2.4\pi} \right) dt = \sum \frac{\mathbf{H} \mu \mathbf{H}}{2.4\pi} = T.$$

Work done by impressed forces=

$$\sum \int h G dt = \sum \int \frac{h \mu \dot{\mathbf{H}}}{4\pi} dt = \sum \frac{h \mu \mathbf{H}}{4\pi} = T_1 = \sum \left(h + \frac{\mathbf{F}}{4\pi} \right) \mu \mathbf{H} = \sum \frac{\mathbf{H} \mu \mathbf{H}}{4\pi} = 2T.$$

$$\mathbf{H} = \mathbf{h} + \mathbf{F} = \mathbf{h} + \text{div } \Omega. \quad \mu \mathbf{H} = \mu \mathbf{h} + \mu \mathbf{F}. \quad \sum \mathbf{F} \mu \mathbf{H} = \sum \mathbf{F} \mu \mathbf{h} + \sum \mathbf{F} \mu \mathbf{F} = \sum \text{div } \Omega \mu \mathbf{H} = 0.$$

$$\sum \int h G dt = \sum \int \mathbf{E} J dt + \sum \int \mathbf{H} G dt = \sum \int \mathbf{Q} dt + T - 2T. \quad \int \mathbf{Q} dt = T = Q \text{ mag.}$$

$$\sum \int \mathbf{e} J dt = \sum \int \mathbf{H} G dt + \sum \int \mathbf{E} J dt = \sum \int \mathbf{Q} dt + U = 2U. \quad \int \mathbf{Q} dt = U = Q \text{ elect.}$$

One-half the energy of the transient currents is expended as heat and the other half as the kinetic magnetic energy of the new state of the field.

SUMMARY STATEMENT.

1. Electrostatic case, magnetic energy vanishing, $\sum eC_0t + 2U = \text{Work}$.
2. Magnetic case, electrostatic energy vanishing, $\sum eC_0t - 2T = \text{Work}$.
3. Joule's heat, electrostatic and magnetic energy, $\sum eC_0t + U - 3T = \text{Work}$.

The case of the polar magnetic field from the sun is the second, for which the work of the forces within the sun is supposed to be,

$$\text{Work of impressed forces} = \sum eC_0t - 2T.$$

The first term is the Joule's heat of the final electric current set up, whatever transient electric currents may have occurred within the body of the sun, but may be laid aside from consideration in the external magnetic field.

$$\text{That part of the work} = - \int Qdt - \frac{1}{2} \cdot \frac{\mu}{4\pi} H^2.$$

We have two remarkable results, that the work done in this case is expended—

(1) In cooling the medium throughout the interplanetary magnetic field, as was shown to be the observed fact at the earth from the discussion of the meteorological elements.

(2) In setting up a magnetic field.

Since it has been shown that the work expended in setting up final states of currents of electricity is diminished by the term $2T$ from that which it would be in setting up electric currents in the sun without any external magnetic field, the inference follows that less work is required to bring about equilibrium states on the sun, when once disturbance occurs in its magnetization or in its electric condition, than would be the case if no external magnetic field existed outside it. This seems most remarkable, but it is concluded that the cooling of the external medium and the increase of the external magnetic field calls for less work in the sun to readjust its forces to normal states than would have been the case if they did not thus exist and operate. Hence, instead of being an argument against the direct magnetic action of the sun, the observed external field at the earth becomes the physical verification of the fact that the sun is a highly magnetized body. It adjusts itself by this mode of operation and expends the minimum work. This inference stands so directly contradictory to the conclusions expressed by Lord Kelvin in his anniversary address (*Nature*, Vol. XLVII, p. 108), and which have been quoted against the hypothesis of the direct magnetic action of the sun, that it may be proper to note it in connection with that statement.

RECOMPUTATION OF SOLAR VALUES OF E. H.

On page 402, Vol. II, *Electricity and Magnetism*, Maxwell gives a computation of the electric and magnetic forces developed during the transmission of energy in sunlight, using Pouillet's data. Since Lang-

ley's determination of the solar constant gives nearly twice as great a value as Pouillet's, it will be worth while to recompute the values of E and H, the maximum amplitudes developed in sunlight. Some other derivative numerical values are added.

The corresponding quantities in the polar field are only transient, very variable, and are therefore not available except when integrated. To do this practically is not now possible, since the observational data, referring to the absorption of energy in the atmosphere, is not yet freed from the convective action of currents derived from the general circulation.

TABLE 38.—*Recomputation of the electric and magnetic forces.*

[E and H for Langley's constant of solar energy.]

Data for the transformations.	Thomson.	Intermediate.	Langley.
Constant of solar energy in calories	17. 037	25. 00	30. 00
(1 horsepower= $10\frac{3}{4}$ calories.)			
Solar constant in horsepower per square meter per minute ..	1. 632	2. 895	2. 874
(1 horsepower=550 foot-pounds per second.)			
Solar constant in foot-pounds per second	897. 7	1317. 3	1580. 8
(1 square meter= 10.7641 square feet.)			
Solar constant in foot-pounds per second on 1 square foot =	83. 4	122. 4	146. 9
energy of strong sunlight.	(Maxwell)		
(1 foot-pound= 0.13825 kilogram meter.)			
Solar constant in kilogram meters per second on 1 square	124. 1	182. 1	218. 5
meter.	(Poincaré)		
(Velocity of light= 9.838×10^8 feet per second.)			
Energy in a cubic foot of sunlight in foot-pounds: or the	.0000000848	.0000001244	.0000001493
pressure on 1 square foot placed normal to ray.	(Maxwell)		
(Velocity of light= 2.9986×10^8 meters per second.)			
Energy in a cubic meter of sunlight in kilogrammeters; or	.0000004189	.0000006074	.0000007288
the pressure on 1 square meter placed normal to ray.	(Poincaré)		
Hence, E electric force	5.673×10^6	6.872×10^6	7.528×10^6
H magnetic force	0. 01892	0. 02292	0. 02511

(Maxwell used $V = 310900000$ meters per second.)

$$E = 7.5 \times 10^6 \text{ C. G. S.} = 7.5 \text{ volts.}$$

$$H = 0.02500 \text{ C. G. S.}$$

$$U = \frac{cE^2}{8\pi} = \frac{\mu H^2}{8\pi} = T = 0.000025 \text{ C. G. S.}$$

$$W = v(U + T) = VEH = 1.875 \times 10^7 \text{ C. G. S.}$$

$$F = \frac{1}{v^2} \frac{dW}{dt} = \frac{\mu c}{v^2} \frac{d}{dt} V \dot{B} = V \dot{D}B + V \dot{D}\dot{B}$$

$$F = V \left(kE + \frac{c}{4\pi} \dot{E} \right) \mu B + \frac{c}{4\pi} \mu VEH = VJB + 4\pi VDG.$$

F = Electromagnetic force + magnetoelectric force, these being mechanical or translatory pressures.

The electromagnetic force can exist in steady states, and it is accompanied by dissipation of energy. The magnetoelectric force can exist only in the transient states. Hence the electromagnetic radiation exerts a steady pressure along the ray of sunlight. The magnetoelectric radiation emits temporary mechanical pressures during the changing of the strength of the polar field of the sun. We may therefore properly speak of the two radiations from the sun, provided the distinction between these two kinds is carefully maintained. To confuse them is an error of analysis.

A purely physical question now remains to be answered. If a magnetic polar line consists of a magnetic force parallel to the direction of **B** and a system of circular electric currents surrounding it in a vortex ring (see Barker's *Physics*, p. 803; Ebert's *Kraftfelder*, chapter 8, and other authors), how are these forces related to changes of temperature of a medium such as the atmosphere? We know that an increase of temperature of the air diminishes the magnetic force of a magnet placed within it, and vice versa. Now, what goes on to do this? The chapter of J. J. Thomson, "Applications of dynamics to physics," on Temperature, No. VI, is very instructive, and should be carefully considered. Till this subject is fully worked up in the laboratory, we may refer to it as one of the unsolved problems as regards the principles of radiation.

Closely connected with this inquiry is a second problem: What are the peculiar mechanical forms of the variations in the vortical system which permits the transfer of energy from the sun to the earth, through so great a distance as 135,000,000 miles, for example? The treatment of the forces as a problem of dynamics instead of statics is apparently the proper method of procedure. Furthermore, the question arises, What is the cross connection between the electromagnetic and the polar magnetic fields, especially in the problem of the dissipation of energy in atmospheric absorption and radiation, accompanied by changes in the wave lengths? All these topics lie beyond the province of this bulletin, but they are nevertheless of much importance.

FUNCTIONAL VARIATIONS IN THE MAGNETIC AND METEOROLOGICAL ELEMENTS.

In view of this hiatus in knowledge of the laws of physics, also considering the total lack of magnetic observations in the Northwest of the United States, and having regard to the components of temperatures and pressures derived from direct energy, intermingled with air in convection currents, it is a most difficult matter to determine what the functions between variations in the magnetic field and the corresponding changes in the meteorological elements of the air really are. As an approximate solution, I have assumed that the synchronism, taken year by year, between these systems is proportional. This amounts to supposing that if the sunlight field acts alone, the mean annual values would show no secular changes, and that therefore the observed simultaneous variations are due to the polar magnetic field alone. Hence the changes are proportional to the required functional relations. From this data (see Table 29) the following results have been derived:

Variations taking place simultaneously:

In the maximum field (auroral belt)	0.000050 C. G. S.
In the European field (also United States)	0.000010 C. G. S.
In the external coronal field (near the earth)	0.000030 C. G. S.

To these correspond, when the above changes are maintained for a year, as is the case in the northwest of the United States and West Canada:

Change in the mean annual pressure, an increase,	0.02 inch.
Change in the mean annual temperature, a decrease,	2° F.
Change in the mean annual pressure amplitude,	0.01 inch.
Change in the mean annual temperature amplitude,	0.2° F.

During certain years in the Dakotas the pressure averages higher and the temperature lower; the average swing of the oscillations from high to low and from warm to cold, taken day by day, is less; and this takes place in years of increased magnetic force from the coronal field in the proportion given above.

In order to show how widely these changes occur from year to year, it is found in the sun-spot cycle 1878-1890 that the following changes took place in those districts:

Range in the European magnetic horizontal component,	0.000060 C. G. S.
Range in the external solar coronal field,	0.000180 C. G. S.
Range in the maximum solar (auroral) field,	0.000300 C. G. S.
Range in the northwest (the Dakotas) pressures,	0.10 inch.
Range in the northwest temperatures,	7° F.
Range in the northwest pressure amplitude,	0.06 inch.
Range in the northwest temperature amplitudes,	1° F.

These relations may need modifications whenever the scientific data warrants an improvement, but they serve to show the general connection between the various quantities involved.

THE GENERAL RELATIONS TO THE GAUSSIAN POTENTIAL OF THE EARTH AND ITS SECULAR VARIATIONS.

It is evident that the general position taken in this bulletin is in accord with the results of the recent analytical calculations of the earth's potential from observations, in so far as it concludes that there is a varying potential outside the earth impressed upon the inside potential. There is, however, a wide divergence in regard to the source of the external field. The opinions quoted are quite uniform in the view that its seat is to be found in the hypothetical electric currents of the rarefied upper atmosphere. Our result is to attribute it to two external fields, having their seat in the sun, interacting upon each other and upon the earth's internal potential. It is clear that these fields possess all the properties required by the analysis of the observations, as herein described, to account for the phenomena. The electric air currents are merely equivalent to the magnetic fields, and in themselves these equivalents have no advantage over the other in the discussion, unless they can be primarily shown to really exist.

Briefly, the argument stands as follows: Admitting that electric currents exist in the atmosphere, as must be the case if there is any

variation of the magnetic potential, we have shown that the magnetic fields, in addition to that effect, exhibit such peculiar properties as to render the explanation intelligible only by placing their seat outside the earth's atmosphere, and specifically in the sun. If the source of the variations under discussion is only within the earth's atmosphere, how is the periodicity and the inversion found in the observations to be accounted for? Also, how is the eleven-year system of synchronous variations of the earth and the sun to be explained, unless we suppose that the earth has power enough to change the state of the sun itself, an idea which seems inadmissible. Several objections to ascribing the variations of the earth's field to the atmospheric convection currents of meteorology have been already mentioned, and these must also be suitably overcome. It is admitted that during the mutual readjustments of the magnetic fields currents of electricity exist throughout the atmosphere; also a change in the wave lengths of the electromagnetic external fields may be a source of the atmospheric electricity; but these subjects must be more fully studied, if possible, before a decisive statement can be offered. The synchronism between the solar and the terrestrial phenomena, the periodicity and inversion of type in the polar field, the peculiar distribution of the magnetic vectors in the electromagnetic field, are therefore the chief points to explain on the atmospheric electric-current theory. These currents, as well as the earth electric currents, are necessary consequences of the interaction of the three fields described, including their own variations in strength and the induced variations due to motion of the planet. But it is hardly possible to consider such electric currents as the true source of all the phenomena heretofore mentioned in detail.

GENERAL SUMMARY.

A summary of the contents of this bulletin indicates that the old problem of the causal connection between certain solar and terrestrial phenomena has been brought one stage nearer its solution. The investigation was carefully founded upon the observations of the magnetic and meteorological elements, and it has been thought proper not to encumber the exposition with much computation, though the necessary working formulæ are collected together for the convenience of the reader. No hypothesis was presupposed in the discussion of the observations which lead to the residuals obtained, but certain deductions were afterwards drawn from them which seem to be warranted by the facts of the case. Among the leading conclusions thus deduced from the observations may be mentioned:

1. The determination and practical use of a period of the synodical rotation of the sun, 26.67928 days, which seems to hold good for at least a half century.

2. The construction of a typical curve, which represents the relative intensity of the normal magnetic field of the sun at the distance of the earth.

3. The detection of this curve in solar and terrestrial phenomena, together with its inversion during the passage of the earth about the sun.

4. The statement of several arguments in favor of the direct magnetic action of the sun upon the earth.

5. The vectors of the lines of the solar magnetic field as distorted by the earth, and the conclusion that the outer shell of the earth is alone permeable to such lines of force.

6. The analysis of the diurnal variations of the needle, and the conclusion that the electromagnetic field of the sun acts like a uniform magnetic field upon such a configuration as the earth, independent of the coronal field, its axis of magnetization being at right angles to the direction of the field.

7. The inference that the earth's atmosphere is thrown out of equilibrium by a uniform heating on the tropical zones, together with an intermittent cooling upon the polar cap, the latter being caused by the direct magnetic field of the sun.

8. An outline in Bulletin 20 of the scheme of the relation of these systems of force to the circulation of the air, whereby a modification of the commonly accepted theory of cause of the formation of cyclones is suggested.

9. The cloud work now being prosecuted by the Weather Bureau will probably afford the data necessary to settle this branch of the problem.

10. It is very desirable that magneticians should establish some permanent observatories, especially in the polar regions of North America and the northwestern United States, in order that these problems may be more efficiently studied.

This bulletin may properly be concluded with an estimate of the probable value of this magnetic polar field in forecasting. No negative or adverse opinions can be accepted as final regarding its practical uses, because it has not been tried; while, on the other hand, it has been shown that the magnetic field is intimately associated to some extent with the production of the weather conditions. The force is itself extraordinarily sensitive, too much so for very simple operations and unconstructed observers, till our instruments are modified. It has a great range of operation in space and time, being in fact the golden thread of continuity running through the otherwise apparently lawless succession of weather variations. The mean curve has a forecasting power to the amount, approximately, of 75 per cent in the Dakotas, so far as the broad features of the highs and lows are concerned, and it is especially useful in the classification of all meteorological data. It contains a very promising method of finding a solution of the problem of

the causes of the marked seasonal changes of the weather in the United States. Next to the barometer and thermometer a magnet is the most valuable instrument in meteorological science. There are doubtless difficulties to overcome in order to reduce the subject to its practical application in the service of the Weather Bureau, but there are grounds for hoping that this can be done.

The renewed interest during recent years in the subject of cosmical magnetism, joined to the great advancement in the general knowledge of electricity and magnetism, warrants the expectation that much practical advantage can be gained by a complete understanding of the laws of this department of natural science.

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From U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

CLIMATE OF CUBA.

ALSO

A NOTE ON THE WEATHER OF MANILA.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau,

BY

W. F. R. PHILLIPS,
IN CHARGE OF SECTION OF CLIMATOLOGY.



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LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., May 25, 1898.

HON. JAMES WILSON,
Secretary of Agriculture, Washington, D. C.

DEAR SIR: I have the honor to transmit herewith a brief report on the temperature and rainfall, and some other climatic features of the Island of Cuba, which has been somewhat hastily compiled by Dr. W. F. R. Phillips of this office and, also, a note on the weather of Manila.

Meteorological information regarding the Island of Cuba is very scant, and the data compiled in the various tables of the accompanying report represent about all the precise meteorological information to be had for the Island. For the purpose of comparison, the temperature, rainfall, and number of rainy days at Washington, D. C., and New Orleans, La., have been introduced in several of the tables (Nos. 1, 2, and 3), the data being printed in bold-faced type to attract special attention. It will perhaps not be inappropriate to emphasize several points upon which there may be misapprehension. The average summer temperature (June, July, and August) of Habana is 82.0° F., that of New Orleans, 81.6° F., and that of Washington, 75.0° F. The highest temperature recorded in ten years at Habana was 100.6° F., while at Washington the highest temperature has been 104° F. The average annual rainfall at Habana is 51.73 inches, and is less than that at New Orleans, which is 60.52 inches; the rainfall at Washington is 44.70 inches. On page 11 will be found an interesting analysis of the rainfall for thirty years at Habana. During this period five occasions have happened when as much, or more, rain fell in the usual "dry season" as in the "rainy season." The average amount of rain falling in the "rainy season," which extends from May to October, is 32.37 inches. In the same months, the average rainfall for New Orleans is 27.00 inches, and for Washington, 24.10 inches.

I recommend that the report be printed as a bulletin of the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,
Chief of Bureau.

Approved:

JAMES WILSON,
Secretary.

CLIMATE OF CUBA.

INTRODUCTION.

There appears to be very little precise and accurate information obtainable regarding the climate of Cuba. Ramon de la Sagra, in his *Historie Physique de Cuba*, quotes, as the earliest record he had consulted, a year's observations of the barometer and thermometer made in Habana in 1794. The thermometer readings, however, appeared to be in error from some cause or other not known and were considered too inaccurate to use. Trustworthy observations of temperature were made in Habana by D. Antonio Robledo, in 1800, 1801, 1806, and 1807, and by D. Joseph Ferrer, in 1810, 1811, and 1812.

Systematic meteorological observations were begun in Habana about 1850 and kept up for some years by Andre Poey, but the data were probably not published, at least no reference to them can be found in the very complete index of meteorological data of the Weather Bureau.

At only one station have systematic meteorological observations been made and published for any considerable time, and that is the observatory of Belen College, Habana. Observations were begun at Belen College in 1859 and have been continued to the present. The daily meteorological observations made at Belen College have been published with more or less regularity in annual volumes. With one or two exceptions, and then only for relatively short periods, no compilation of the monthly averages has been published.

Apart from the observations of Belen College and the brief records already named, only fragmentary meteorological data for other parts of the island have been found. Temperature observations made in 1796-99 at Ubajay, a village about 15 miles southwest of Habana; two years' observations between 1832 and 1835 at Matanzas; eighteen months' observations in 1839 and 1840 at a place in the interior about 150 miles eastward of Habana, the San Fernando mines; and fragmentary observations at Santiago de Cuba and Trinidad de Cuba comprise all the data to be found.

A good deal of meteorological data, especially of rainfall, is, however, to be had for adjacent and neighboring islands, and which by judicious use may be made to be of considerable service in forming an intelligent idea of the climate, or climates, of Cuba. With this purpose in view, temperature and rainfall data have been compiled from the following places, viz: To the north, Key West, Fla., and Nassau, Bahamas; to the east, Port au Prince, Haiti, San Juan,

Puerto Rico, and St. Thomas; and to the south, Kingston and other stations in Jamaica. To the west there are no islands, and the nearest meteorological station is at Merida, Yucatan. Also for general information and because of some climatic relevancy that may exist, meteorological statistics from the islands of Martinique, St. Vincent, Barbados, and Trinidad have been compiled and introduced. The different statistics are shown more or less in detail in the tables to be found in the text, or appended thereto.

GEOGRAPHICAL POSITION.

With the exception of the northern part of the Bahamas, the large group of islands collectively known as the West Indies lies within the north tropical zone, being situated in the greater part between the Tropic of Cancer and the tenth parallel of north latitude, and between the sixtieth and eighty-fifth meridians of west longitude. The total number of islands comprising the West Indies is somewhat more than 1,000, and the total land area is, in round numbers, about 95,000 square miles. Cuba, Haiti, Jamaica, and Puerto Rico, which comprise little more than three-fourths of the total area of the West Indies, are virtually included between the parallels of 17° and 23° north latitude. The greater part of the land area lies at a considerable elevation above sea level; more than 15,500 square miles lie at an altitude of 1,500, or more, feet above the sea. The Bahamas are the lowest and rise but little above the sea, the highest hill being only 280 feet.

The area of Cuba and its dependent islands is about 43,000 square miles. Its extreme length, measured along a curved line following its center, is 730 miles, and its average breadth about 80 miles. The physical aspect of the interior of Cuba, according to Humboldt, "is gently undulating and like that of England, not more than 280 to 380 feet above the level of the sea. The village of Ubajay, about 15 miles distant from Habana, in a southwesterly direction, is 242 feet above the sea."

The highest part of the island is the range of mountains known as the Sierra Maestra, bordering the southeast coast from Cape Cruz to Cape Maysi. The highest mountain peaks are the Pico de Tarquino, 7,670 feet, the highest point in the island; Gran Pedra, 5,200 feet; Junque and Ojo del Toro, 3,000 feet. From this range there extends very nearly through the center of the island a general ridge of very much less elevation, though in the extreme western part it rises, in the Pan de Guajaibon, to an elevation of 2,530 feet. This ridge divides the island into two general watersheds, from which its rivers flow in northerly and southerly directions, respectively.

CLIMATE.

The climate of the West Indies presents, with respect to both

temperature and rainfall, considerable variations from the generally conceived idea of tropical uniformity. These variations are largely, if not entirely, caused by differences in altitude and position with respect to the prevailing winds of the zone.

Meteorologically considered the West Indies lie between the sea-level isotherms of about 77° and 80° , and have an average annual rainfall of about 60 inches, the greater part of which falls from May to October. The average humidity of the atmosphere is approximately about 75 per cent of the amount required for saturation at the average annual temperature. The prevailing winds are from the east and north of east, the "northeast trades," and blow with great regularity and uniformity.

TEMPERATURE.

The average annual temperature of Habana, as determined from the observations at Belen College, made during the decennium 1888-1897, may be stated in round numbers as 77° F. In this decennium the highest annual temperature was 77.2° , and this occurred upon three occasions; and the lowest annual temperature was 76.1° , and happened upon only one occasion, showing in the ten years an extreme range in annual averages of but 1.1° F. It would, therefore, seem probable that the mean temperature for the decennial period 1888-1897 is about a true average for Habana for any long period. The warmest month at Habana is July, with an average temperature of 82.4° F. The warmest July in this decennium had an average temperature of 83.5° F., and the coolest July a temperature of 81.7° F. The warmest single month in the decennial period was August, 1888, when the average temperature was 84.2° F. The coldest month is January with an average temperature of 70.3° F., and the warmest and coldest Januaries in this decennium were, respectively, 73.4° F. and 67.5° F. The highest temperature recorded was 100.6° F. in July, 1891, and the lowest, 49.6° F. in February, 1896. For Matanzas, on the coast about 50 miles east of Habana, there is a record for two years, beginning in August, 1832, and ending in July, 1833, and again beginning in January, 1835, and ending with December of the same year. From this record the mean annual temperature at Matanzas appears to be about 78° . The highest temperature is recorded as 93° , and the lowest as 51° .

At Santiago, on the extreme southeast coast, the temperature is apparently higher than on the northern and western coasts, and from the meager data available appears to be about 80° , with an average difference between the warmest and coldest months of about 6° F. A very short fragment of a record of temperature has been found for Trinidad de Cuba, about midway on the southern coast, giving the average temperature from December, 1851, to March,

1852, for the hours of 7 a. m., 2 p. m., and 7 p. m., as 72.8°, 78.7°, and 75.3° F., respectively, and the observer remarks that during that period the highest temperature recorded was 84°, and the lowest 64.5° F., and the greatest range in any twenty-four hours was 9.5°, which occurred upon the day having the highest temperature.

For the interior of the island only two temperature records have been found, namely, for Ubajay, and the mines of San Fernando. Ubajay is, or was at the time, a village about 15 miles southwest of Habana, and about 242 feet above sea level. Its average temperature from four years' observations was 73.6° F. The record is quoted by Baron Humboldt and was made during 1796-1799. The place given as San Fernando mines is about 150 miles eastward of Habana, and is 554 feet above sea level. The temperature record is for the year 1839, and shows an average of 75°. From these records the average annual temperature of the interior of the island would appear to be considerably lower than on the coast.

The shortness of the records at Ubajay, Matanzas, and San Fernando mines, and the additional fact of the chronological differences in the several series of observations above quoted preclude any direct comparison between the temperatures at the different places. However, the following table is interesting enough for insertion :

Months.	Ubajay, 1796-99.	Habana.				New Orleans, 1873-91.
		1794.	1800-1, 1806-7.	1810-12.	1888-97.	
January.....	65.3	74.1	65.3	70.0	70.3	54.4
February.....	67.5	75.6	70.0	72.0	72.0	58.5
March.....	66.9	78.8	72.0	75.7	73.2	62.6
April.....	70.0	80.6	75.4	79.0	76.1	69.0
May.....	76.1	82.6	79.7	82.6	78.8	74.9
June.....	82.2	84.9	88.7	82.1	81.5	80.6
July.....	88.7	87.6	85.3	83.3	82.4	82.4
August.....	83.3	86.9	83.6	83.8	83.2	81.8
September.....	79.5	86.7	80.6	82.0	80.7	78.4
October.....	76.5	83.1	78.4	79.5	78.1	70.4
November.....	66.3	81.0	73.6	75.6	75.3	61.2
December.....	62.2	75.0	70.0	72.0	71.4	56.0
Year.....	73.6	81.5	77.0	78.3	76.8	69.2

The temperatures given above for Habana for the years 1800, 1801, 1806, 1807, and 1810-12 are upon the authority of Humboldt and Ramon de la Sagra. Those for Habana for 1888-97 are from the records of Belen College. The data given for Habana for 1794 are the observations already referred to as rejected by Ramon de la Sagra. The New Orleans data are from the Weather Bureau records, and are introduced for the purpose of comparison.

From observations made in Jamaica, at different altitudes, it appears, according to Maxwell Hall, that near the sea level the mean temperature decreases about 1° F. for every 315 feet. The following

table showing the decrease of temperature as affected by elevation in Jamaica is given by Maxwell Hall:

Station.	Elevation.	Barometric pressure.	Temperature.			
			Mean.	Maximum.	Minimum.	Range.
	<i>Feet.</i>	<i>Inches.</i>	°	°	°	°
Kingston.....	50	30.96	78.1	87.8	70.7	17.1
Kempshot.....	1,773	28.20	73.7	80.5	68.0	12.5
Chinchona Plantation.....	4,907	26.27	68.6	68.5	57.5	11.0
Portland Gap.....	5,477	24.71	59.7	69.0	54.6	14.4
Blue Mountain Peak.....	7,428	23.14	55.7	71.1	46.3	24.8

This table presents some interesting features. It will be noticed that the mean and minimum temperatures fall progressively as the altitude increases, and likewise the maximum temperature till an elevation of about 5,000 feet is reached, after which it begins to rise. The diurnal range of temperature is, also, shown to undergo first a decrease and subsequently an increase.

It may be stated, generally, that the individual monthly temperatures depart but little from their normals. On the other hand, although the information is not in form for statistical treatment, there is testimony to show that sudden variations in the temperature of the day are not unusual or unknown. Humboldt states that changes in temperature occur very suddenly in Habana, and gives an instance of the fall of the thermometer in the shade in the space of three hours from 89° to 74°, a very considerable fall for the tropics certainly, and one that occurring on a summer's day even in the temperate latitudes would impress itself quite noticeably.

The maximum temperature is reached between noon and 2 o'clock in the afternoon, and the minimum between dawn and sunrise. The average diurnal range of temperature is about 10°. The general course of the temperature from hour to hour is fairly accurately shown in the table following, which has been computed from the reports of Belen College:

Month.	A. M.				Noon.	P. M.				
	4	6	8	10		2	4	6	8	10
January.....	64.6	64.2	65.8	70.9	73.6	74.1	73.2	70.9	69.1	67.6
February.....	66.0	65.7	67.6	72.3	75.6	76.8	75.6	72.9	70.7	69.1
March.....	67.3	66.0	70.3	75.7	78.4	79.2	78.1	75.0	73.7	71.1
April.....	70.0	69.6	73.4	79.5	81.3	81.1	80.8	77.9	75.2	73.8
May.....	72.7	72.9	76.8	82.8	83.1	83.8	82.8	80.4	77.5	76.3
June.....	75.0	75.6	81.5	84.9	85.6	85.5	84.0	82.0	79.2	77.7
July.....	75.7	75.9	81.9	86.2	87.1	87.7	85.6	83.5	80.2	78.8
August.....	76.3	76.3	81.1	85.8	86.9	86.7	85.5	83.3	80.6	79.5
September.....	75.6	75.4	79.8	83.8	85.1	84.6	83.7	81.3	79.3	78.3
October.....	73.9	73.6	76.6	80.6	81.9	82.0	80.4	78.3	77.0	76.1
November.....	71.1	70.7	73.4	77.5	79.3	79.2	77.9	75.7	74.5	73.4
December.....	67.3	66.9	68.7	73.4	75.2	75.7	74.5	72.3	70.9	69.8

ATMOSPHERIC MOISTURE.

Relative humidity.—The relative humidity of the atmosphere appears to be fairly constant, as far as can be determined from the observations available. It averages about 75 per cent of saturation. The mean relative humidity of the different months differs hardly enough to characterize one month as being drier or damper than another.

From observations made at Habana at different hours of the day it appears that the diurnal range of the relative humidity is considerable, varying from a maximum of about 88 per cent in the morning to a minimum of about 64 per cent at noon. The following table shows the average relative humidity at certain hours of the day:

Month.	A. M.				Noon	P. M.				
	4	6	8	10		2	4	6	8	10
January.....	84	85	82	70	63	63	65	96	77	79
February.....	85	85	81	68	63	61	63	70	76	79
March.....	85	85	78	64	58	58	63	70	75	79
April.....	82	84	73	61	68	59	60	67	73	76
May.....	85	85	73	63	63	63	65	69	76	78
June.....	89	89	77	67	67	67	70	74	81	84
July.....	88	88	76	64	63	64	67	70	78	82
August.....	87	88	78	64	63	64	67	73	78	82
September.....	90	90	83	73	70	71	74	78	82	85
October.....	88	89	80	73	69	69	73	78	81	84
November.....	86	87	82	71	68	68	72	77	80	82
December.....	83	83	79	67	64	64	67	73	75	77

Absolute humidity.—The absolute humidity is very great. At Habana the average is about 7.5 grains of vapor to the cubic foot of air, and at Kingston, Jamaica, it is about 8.0 grains to the cubic foot. At Habana the absolute humidity varies from 6.2 grains per cubic foot in January to 8.9 grains in September, and at Jamaica from 7.1 grains in January to 8.8 grains in September.

RAINFALL.

The rainfall shows to a greater degree than the temperature the influence of locality and season of the year. The average rainfall for Habana is about 52 inches for the year, and for Kingston, Jamaica, about 32 inches, while the average for the whole of Jamaica appears to be from about 65 to 67 inches. The greatest rainfall is reported, however, from the island of Martinique, and varies from 133 inches at Fort de France to 93 inches at St. Pierre. The rainfall is, as a rule, greater on north and east coasts than on south and west coasts.

The fall of rain is greatest during the months of May to October. On an average the greatest rainfall occurs in October, and the next greatest in June. During the months of July and August there appears quite a noticeable falling off in the amount of aqueous precipitation in comparison with the months of June and October.

The description of the rainfall of Cuba virtually resolves itself, so far as present information goes, into that of the rainfall at Habana. The short and fragmentary records at Matanzas, Santiago de Cuba, and the San Fernando mines can not be considered as representative of the character and quantity of rainfall in their respective localities.

Rainfall at Habana.—Observations have probably been taken continuously at Belen College Observatory since 1859, but the records on file in the Library of the Weather Bureau show a hiatus from 1876 to 1884, inclusive. In the combined periods, 1859–75 and 1885–97, the greatest annual rainfall was 71.40 inches in 1867, and the smallest fall was 40.59 inches in 1861. The average rainfall for the thirty years was 51.73 inches. The monthly rainfall for the thirty years is shown in detail in Table IV.

Rainy season.—The season of heavy rainfall for the West Indies in general begins with May and ends with October, as has already been stated.

The rainy season at Habana begins in the latter part of May and the first of June and ends with October. Relatively the greater bulk of the rain falls during the months from June to October. The average rainfall for this period is 32.37 inches, or 63 per cent of the annual fall. The following table shows the amount falling in the rainy and dry seasons of each year of the periods 1859–75 and 1885–97:

Amount of rainfall at Habana.

Year.	Rainy season (June to October, inclusive, 5 months).		Dry season (November to May, inclusive, 7 months).	
	Amount.	Per cent of annual.	Amount.	Per cent of annual.
1859.....	28.44	63	16.40	37
1860.....	27.80	63	16.65	37
1861.....	28.76	71	11.83	26
1862.....	26.09	70	15.30	30
1863.....	23.07	51	22.08	49
1864.....	26.53	60	19.35	40
1865.....	25.39	54	21.57	46
1866.....	33.39	78	12.56	27
1867.....	45.66	64	25.74	36
1868.....	23.00	44	37.80	56
1869.....	23.64	41	33.15	59
1870.....	33.38	70	18.89	30
1871.....	39.52	78	14.23	27
1872.....	27.56	56	20.23	42
1873.....	24.12	47	27.35	53
1874.....	42.11	79	11.07	21
1875.....	27.63	65	14.63	35
1885.....	26.79	56	21.38	44
1886.....	47.49	74	17.04	26
1887.....	33.38	66	16.95	34
1888.....	23.97	45	29.54	55
1889.....	35.71	60	24.08	40
1890.....	26.15	50	28.41	50
1891.....	28.02	65	20.51	35
1892.....	49.49	85	8.81	15
1893.....	38.26	64	21.64	36
1894.....	28.08	75	12.68	25
1895.....	36.78	69	17.07	31
1896.....	31.09	60	19.97	40
1897.....	27.70	60	18.51	40

In the island of Jamaica the rainy season appears to begin in May and end, as at Habana, in October. At Port au Prince, Haiti, and San Juan, Puerto Rico, it begins in April and ends at the former in October and at the latter in November, while in the island of St. Thomas, to the east of Puerto Rico, the rainy season appears to be embraced in the months of October, November, and December; also in other islands of the Lesser Antilles irregularities are observed.

Rainy days.—The number of days on which rain falls is, upon the whole, considerable, about one day out of three at Habana and almost two days out of every three at Fort de France. The general character of the rainfall appears to be heavy downpours of short duration, and this is particularly the case during the summer months, or as the time is more generally known in the West Indies, "the rainy season." The following table shows the greatest twenty-four hour rainfall for each month, as recorded at Habana, during the decennium 1888-97:

1888-97.	Greatest rainfall in 24 hours.	1888-97.	Greatest rainfall in 24 hours.
	<i>Inches.</i>		<i>Inches.</i>
January	3.98	July	3.28
February	2.79	August	2.70
March	3.06	September	3.78
April	2.46	October	5.82
May	6.57	November	3.72
June	4.65	December	2.22

Notwithstanding the frequency of rain during the summer months they do not present the greatest number of cloudy days. The rains, "although copious, are of short duration, and those days on which showers do fall are, in general, perfectly cloudless. It may almost be said that during these months no clouds are to be seen in the atmosphere, except while the showers are falling, while in other months cloudy days sometimes occur without rain."

WIND.

The prevailing winds of this region are the "northeast trades." Except when influenced by the passage of cyclonic and anti-cyclonic areas the wind blows steadily from points between east and north. During the passage of storms and areas of high barometric pressure however, the winds may blow from any direction, being governed in this regard by the location of the center of cyclonic or anti-cyclonic activity. In the winter season, cold waves in the United States, when extending far to the southward, cause cold, northerly winds, or "northers," along the north Cuban coast.

The average velocity of the wind at Habana is about 7.5 miles an hour. The velocity, however, varies considerably with the season, being highest in winter, when its average velocity is 8.5 miles an hour, and lowest in summer when its velocity is 6.5 miles an hour.

The velocity is also higher on northern coasts than on southern coasts, as is shown by comparison of the anemometer records of Habana and Kingston. The diurnal variation in the velocity of the wind is much more pronounced than the seasonal variation. The following table shows the average velocity of the wind at certain hours of the day at Habana, Cuba, and Kingston, Jamaica:

Hour.	Miles an hour.	
	Habana.	Kingston.
4 a. m.....	4.3	2.0
6 a. m.....	4.5	2.0
8 a. m.....	6.5	2.1
10 a. m.....	9.2	4.3
Noon.....	10.7	6.9
2 p. m.....	11.4	7.6
4 p. m.....	10.7	6.6
6 p. m.....	8.7	4.5
8 p. m.....	6.9	2.7
10 p. m.....	5.6	2.1

In climates having such high temperatures and humidities as shown for the West Indies, the velocity of the wind and its constancy are of the greatest importance to both comfort and health.

CLOUDS.

But little can be said of the clouds. Maxwell Hall states that:

During the winter months there is much detached stratus; during the summer months there is much cumulus, which keeps the afternoons cool, especially as the cumuli soon degenerate into strato-cirrus, and then disappear, leaving the nights perfectly clear. When rain begins to fall from a large cumulus a quantity of cloud is poured into the air from the top of the cumulus as smoke from a factory chimney. This takes place in all parts of the world when rain falls from cumulus, but in the temperate zones only a little *false cirrus*, or cirri-form is thrown off. In Jamaica the process is on a gigantic scale, and the cloud is spread out as a sheet, far and wide, so as to shade the land for an hour or two from the direct rays of the afternoon sun. It is, therefore, a common cloud in Jamaica. Its texture at first is thick and woolly, but as it spreads the sheet becomes thinner * * * and it finally disappears a little after sunset, leaving the evening sky perfectly clear.

STORMS.

Thunderstorms, with much electrical display, are of frequent or almost daily occurrence, but little damage results from them. The West Indies are more or less subject during each summer to one or more severe tropical storms or hurricanes. These storms are more likely to occur in the months of August, September, and October.

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TABLE I.—Average monthly and annual temperature, in degrees Fahrenheit.

Place.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Series.		Record.		Authority.†
														Begin.	End.	Years.	Months.	
Washington, D. C.	32.2	35.9	41.3	53.0	63.9	72.2	76.9	74.9	67.8	56.2	44.9	39.2	54.7	1871	1885	25	.....	(8)
New Orleans, La.	53.8	58.1	63.0	69.0	74.8	80.5	83.4	81.5	74.3	63.8	60.7	55.5	69.3	1871	1895	25	.....	(8)
Key West, Fla.	70.6	72.2	73.0	76.4	79.6	83.0	84.4	84.1	82.8	78.9	74.7	70.5	77.5	1871	1895	21	.....	(8)
Havana, Cuba.	70.3	72.0	73.2	76.1	78.8	81.5	83.4	83.2	80.7	78.1	76.3	71.4	76.8	1888	1897	10	.....	(4)
Ubalay, Cuba*	64.5	67.5	69.8	70.0	73.0	82.2	83.5	83.2	82.0	76.5	69.2	63.2	73.5	1796	1799	4	.....	(11)
Mines of San Fernando, Cuba..	69.9	71.4	73.2	74.6	77.9	78.9	80.5	80.6	78.6	76.9	72.7	67.9	75.0	1889	1899	1	.....	(1)
Matanzas, Cuba.	72.6	72.0	75.6	80.1	80.8	82.2	81.5	80.6	83.2	78.8	77.7	74.8	78.4	1889	1895	2	.....	(1)
Santiago, Cuba.	77.0	77.0	77.0	80.0	81.0	83.0	86.0	88.0	83.0	81.0	79.0	76.0	.....	1881	1892	1	.....	(6)
San Juan, Puerto Rico	76.6	75.7	76.6	77.9	79.2	81.5	81.1	81.3	81.0	80.6	79.2	76.5	76.8	1876	1895	12	.....	(6)
St. Thomas	80.2	78.4	78.0	79.5	79.5	80.6	82.9	83.3	83.8	84.0	83.3	81.9	81.0	1860	1863	3	.....	(2)
Kingston, Jamaica	74.6	74.7	75.8	77.9	79.4	80.8	81.1	80.4	80.1	78.9	77.8	75.7	78.1	1860	1860	10	.....	(12)
Barbados†	73.6	73.4	73.5	76.2	78.2	76.7	76.7	76.7	76.7	76.9	76.1	75.0	75.6	.....	.....	20	.....	(16)

* About 15 miles southwest of Habana.

† Country district in island.

‡ See page 14.

TABLE II.—Average monthly and annual rainfall, in inches and hundredths.

Place.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Series.		Record.	Authority.	
														Beginns.	Ends.			Years.	Months.
Washington, D. C.	3.50	3.15	4.08	3.16	3.90	4.28	4.84	4.44	3.83	3.27	2.83	3.10	43.61	1871	1871	25	.....	(8)
New Orleans, La.	5.17	4.53	5.35	5.28	4.78	6.48	6.50	6.02	4.70	3.25	4.50	4.58	60.53	1871	1871	25	.....	(8)
Key West, Fla.	5.10	1.70	1.20	1.80	3.30	4.10	4.30	5.10	7.50	5.30	2.50	1.70	40.10	1871	1871	25	.....	(8)
Nassau, New Providence ..	1.97	1.27	0.54	1.70	7.00	6.38	4.17	6.65	7.74	5.90	1.88	2.10	46.75	1840	1846	8	.....	(16)
Havana, Cuba.	2.82	2.52	2.50	1.46	5.15	8.29	5.09	5.43	7.62	8.49	4.94	1.98	55.14	1888	1897	10	.....	(4)
Do.	2.71	2.27	1.83	2.68	4.47	7.16	5.05	6.02	6.71	7.42	8.08	2.15	51.73	1869	1897	30	.....	(4)
Matanzas, Cuba.	3.16	2.99	2.49	2.99	20.86	14.56	9.57	11.50	7.80	7.47	8.88	1.40	55.29	1885	1885	1	.....	(11)
Mines of San Fernando, Cuba.	2.74	0.59	0.76	0.59	0.59	0.48	1.94	5.20	8.96	8.90	2.36	1.77	38.82	1861	1862	1	.....	(11)
Santiago, Cuba.	0.51	2.88	3.84	3.25	9.05	4.74	4.81	6.66	6.85	10.07	6.71	5.59	67.41	1870	1879	10	.....	(14)
Jamaica†	4.46	2.88	2.49	4.18	9.07	7.77	4.32	6.83	6.87	8.04	5.08	5.60	66.54	1880	1890	10	.....	(14)
Do.	0.96	0.82	1.59	1.02	6.00	5.51	2.15	4.09	3.59	4.09	1.22	1.50	33.64	1880	1890	10	.....	(12)
Ross' View.	3.11	5.28	1.50	3.54	1.46	3.15	1.98	5.51	6.10	12.30	8.74	3.11	54.33	1873	1873	2	.....	(3)
Port au Prince, Haiti.	1.23	2.35	3.55	9.52	12.43	4.50	4.10	5.51	5.53	6.43	3.98	1.49	61.17	1863	1867	4	.....	(16)
San Juan, Puerto Rico.	3.83	1.90	2.67	5.35	6.38	5.98	5.83	6.21	5.33	5.63	6.43	4.41	86.23	1876	1896	12	.....	(6)
St. Thomas.	2.87	2.24	0.79	2.56	1.50	2.99	3.85	2.82	2.99	12.46	16.10	12.05	183.11	1867	1872	10	.....	(2)
Fort de France, Martinique.	8.08	4.64	4.29	3.96	6.38	14.29	15.59	20.67	14.41	12.46	8.58	7.40	92.66	1867	1872	10	.....	(2)
St. Pierre, Martinique.	4.80	3.90	3.11	3.54	6.59	9.76	8.89	14.33	11.03	9.46	8.58	7.40	92.66	1860	1874	15	.....	(8)
Kingstown, St. Vincent.	4.23	2.54	3.84	3.86	6.59	8.99	8.39	8.30	8.30	9.13	8.89	4.45	57.74	1881	1886	5	.....	(8)
Barbados†	2.36	2.08	2.84	1.70	3.54	7.61	7.89	6.75	10.06	9.12	8.89	4.50	60.56	.....	.....	.....	.....	(15)
Royal Bot. Gardens, Trinidad.	2.83	1.80	1.47	1.99	3.54	4.45	5.70	7.24	6.24	8.09	7.08	4.50	57.74	1863	1868	17	.....	(8)
Merida, Yucatan.	1.02	0.53	0.70	1.88	2.55	7.96	9.13	10.45	7.53	6.87	6.89	4.72	33.86	1896	1897	3	.....	(17)

† Average for entire island.

TABLE III.—Average number of days on which rain fell.

Place.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Series.		Record.		Authority.
														Begin.	End.	Years.	Month.	
Washington, D. C.	12.1	10.1	8.3	7.9	12.2	10.2	11.1	11.2	9.9	8.8	10.1	10.4	129.2	1871	1881	10	.....	(8)
New Orleans, La.	11.2	8.4	6.8	4.5	9.9	12.6	15.8	14.4	10.8	7.4	9.4	11.9	131.7	1871	1885	14	.....	(8)
Key West, Fla.	8.1	6.8	4.9	4.5	8.5	11.8	12.6	14.5	16.4	12.4	8.0	7.2	117.7	1871	1895	24	.....	(8)
Havana, Cuba.	7.5	5.7	5.5	4.6	9.3	12.8	12.7	12.6	15.4	15.1	10.2	8.5	119.9	1868	1897	15	.....	(4)
Mines of San Fernando, Cuba.	4.0	6.0	9.0	6.0	24.0	21.0	22.0	20.0	16.0	22.0	2.0	6.0	.....	1889	1899	1	.....	(1)
Santiago, Cuba.	2.0	5.0	6.0	9.0	11.0	5.0	5.0	16.0	10.0	11.0	9.0	2.0	.....	1881	1883	1	.....	(8)
Ros's View, Jamaica.	12.2	12.0	9.4	12.8	9.4	14.2	8.2	12.6	17.8	17.2	21.6	13.8	.....	1869	1873	5	.....	(2)
Denbigh, Jamaica.	4.7	4.4	5.1	5.3	8.5	5.6	5.6	8.2	8.3	11.2	7.6	4.6	.....	.....	.....	.....	.....	(14)
Port au Prince, Haiti.	5.0	10.0	10.0	15.0	19.0	14.0	12.0	16.0	15.0	18.0	12.0	5.0	.....	1863	1867	4	.....	(2)
Fort de Franco, Martinique.	20.4	14.5	13.8	10.9	15.1	20.1	21.5	20.1	18.5	19.9	17.2	19.2	211.2	1867	1873	17	.....	(2)
Barbados†.	17.0	14.7	10.3	11.0	12.0	13.0	13.7	20.7	18.0	19.7	18.0	17.3	.....	.....	.....	.....	.....	(15)
Merida, Yucatan.	5.0	4.7	3.0	1.0	3.7	15.0	15.7	17.3	16.7	10.0	10.0	8.5	.....	1895	1897	3	.....	(17)

† Average for entire island.

TABLE IV.—*Temperature and rainfall at Habana, Cuba.*

MEAN MONTHLY TEMPERATURE.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1888..	73.0	72.9	73.6	75.7	78.4	81.1	82.6	84.2	80.8	79.2	75.0	70.5	77.2
1889..	73.0	72.8	71.8	76.1	79.0	82.2	83.1	81.9	82.2	77.2	76.6	70.5	77.2
1890..	73.4	73.3	72.5	76.2	79.3	82.2	82.6	81.0	79.5	79.0	75.2	70.2	77.0
1891..	69.3	73.6	74.1	74.8	77.7	82.8	83.5	82.2	80.8	76.3	74.1	73.0	78.6
1892..	69.6	70.7	71.1	77.0	79.3	80.1	81.9	81.5	80.6	77.0	73.2	71.4	78.1
1893..	67.5	73.6	74.3	77.9	80.1	81.1	83.6	80.1	79.9	79.2	74.8	71.6	77.1
1894..	71.3	73.5	73.2	78.3	77.9	79.8	81.7	83.6	80.4	76.6	74.8	70.7	78.5
1895..	69.7	66.9	74.1	75.9	79.9	81.9	83.5	83.2	81.1	78.4	75.4	69.6	78.6
1896..	68.7	69.8	72.1	75.4	79.2	82.2	81.9	83.8	81.0	79.3	77.4	71.6	78.8
1897..	69.1	73.9	76.1	76.1	77.9	81.3	81.7	82.2	79.0	77.9	76.1	73.8	77.2
Mean	70.3	73.0	73.2	76.1	78.8	81.5	82.4	82.2	80.7	78.1	75.3	71.4	76.8

ABSOLUTE MAXIMUM TEMPERATURE.

1888..	82.4	86.4	91.4	87.3	96.3	95.7	95.5	96.6	94.1	91.8	86.0	80.6	93.6
1889..	83.1	87.4	84.7	88.5	96.6	96.8	97.7	96.2	93.9	86.4	86.9	80.6	97.7
1890..	86.0	87.1	91.4	92.8	97.9	96.4	99.7	93.1	93.5	89.1	84.4	82.8	99.7
1891..	80.8	85.8	89.1	90.5	93.7	97.7	100.6	91.8	93.8	87.1	85.1	82.0	100.6
1892..	83.0	84.4	89.4	90.1	91.6	94.6	92.8	91.8	93.4	88.8	83.8	83.7	91.6
1893..	80.2	87.3	90.1	91.6	95.4	95.7	92.1	93.9	96.6	91.9	84.0	81.7	95.7
1894..	83.1	84.9	88.7	86.5	93.2	92.8	95.2	93.9	89.1	86.9	86.7	82.6	95.2
1895..	84.4	84.2	87.4	93.6	99.0	95.4	95.2	93.9	89.6	89.4	83.3	82.2	99.0
1896..	80.9	88.5	88.2	85.6	93.6	97.3	92.3	90.7	90.1	89.8	86.7	81.5	97.3
1897..	79.9	87.6	89.0	87.4	86.4	91.6	91.2	93.2	90.3	89.8	86.2	86.0	93.2

ABSOLUTE MINIMUM TEMPERATURE.

1888..	59.4	59.4	62.4	62.8	66.6	69.1	73.2	73.0	72.7	69.1	56.5	55.4	55.4
1889..	57.2	60.4	59.4	62.0	64.4	71.4	73.0	73.5	74.7	65.1	61.0	60.6	57.2
1890..	63.7	61.9	55.0	65.5	69.8	73.0	72.0	71.2	70.9	61.9	64.8	56.7	55.0
1891..	53.8	56.3	60.8	52.9	64.9	72.1	73.3	73.7	71.6	63.3	61.8	63.2	52.3
1892..	54.0	59.0	55.0	64.8	68.2	72.1	71.2	73.1	72.5	61.7	61.2	57.7	54.0
1893..	53.8	57.9	60.6	60.4	66.7	70.7	72.9	73.4	72.5	71.6	63.1	60.8	53.8
1894..	59.0	60.1	60.3	61.5	64.8	70.7	72.1	71.6	72.1	64.8	64.2	51.8	51.8
1895..	55.6	51.4	56.8	61.3	70.9	73.7	73.4	73.7	73.7	66.9	63.4	54.9	51.4
1896..	54.5	49.6	58.3	64.4	66.2	73.0	73.4	73.7	73.6	69.8	67.1	59.0	49.6
1897..	57.2	57.2	59.0	65.5	65.8	71.6	71.6	69.6	72.0	63.7	65.1	60.4	52.2

PRECIPITATION (in inches).

1889..	5.81	0.19	0.78	0.40	2.00	2.95	3.70	7.28	3.94	9.92	5.28	1.29	44.84
1890..	2.02	3.43	0.55	6.02	1.07	7.98	2.78	6.06	6.47	4.59	0.59	2.26	44.45
1891..	0.61	0.59	2.89	2.05	4.43	8.19	4.88	8.39	5.01	7.29	0.63	1.13	40.59
1892..	2.00	1.09	2.22	1.17	3.26	9.20	8.42	5.70	4.90	7.87	2.26	3.18	51.29
1893..	1.48	0.23	2.70	0.28	10.22	8.20	2.14	7.89	4.61	5.23	2.49	4.48	45.10
1894..	4.50	1.43	3.73	2.05	2.59	7.22	5.13	7.09	3.63	5.36	2.33	2.72	47.88
1895..	4.88	2.23	2.70	0.07	4.98	1.17	2.55	5.41	7.26	8.80	5.35	0.17	46.86
1896..	2.01	2.73	0.57	1.23	1.75	3.72	12.23	4.42	6.81	6.11	2.52	1.06	45.95
1897..	2.89	1.16	0.59	1.20	13.26	14.44	6.71	7.19	6.43	10.89	1.47	4.65	71.40
1898..	3.22	2.26	1.21	6.60	3.25	2.99	1.95	2.26	5.99	8.71	8.65	1.81	49.80
1899..	2.08	2.03	2.10	22.57	2.43	4.28	4.13	4.03	7.04	2.56	0.87	1.09	55.79
1870..	1.50	1.62	1.04	2.44	4.70	8.65	8.20	3.15	2.42	9.96	1.96	0.71	46.27
1871..	2.09	0.00	0.25	0.06	6.67	8.92	6.65	8.32	15.92	4.65	0.90	4.25	53.84
1872..	6.29	1.26	1.06	0.19	2.24	1.46	4.08	6.38	8.50	7.14	4.01	3.97	47.86
1873..	5.22	9.41	1.02	4.22	2.28	4.76	1.15	4.52	6.59	6.81	1.63	2.63	51.47
1874..	1.64	1.20	0.11	1.72	2.21	15.25	4.26	6.64	5.22	9.34	1.24	2.65	53.15
1875..	1.72	4.09	1.07	4.18	2.29	1.24	2.26	10.60	10.02	8.41	0.47	0.26	42.21
1886..	2.16	5.54	1.42	1.55	6.25	8.03	0.64	4.52	6.00	7.60	1.22	3.44	45.17
1886..	2.69	1.09	0.73	8.07	3.06	12.62	15.06	10.03	4.52	5.26	0.73	0.67	64.53
1887..	3.23	0.61	3.22	2.69	0.68	15.19	3.21	5.12	2.44	6.42	3.50	3.22	49.23
1888..	0.02	3.07	1.56	0.82	13.53	7.02	4.17	1.45	6.47	3.95	7.47	3.02	53.51
1889..	5.77	4.27	5.05	2.28	1.16	9.20	5.24	9.26	3.21	8.50	3.91	1.49	59.73
1890..	0.52	0.66	0.54	0.06	17.51	1.50	7.13	5.25	12.27	2.00	7.94	1.18	56.55
1891..	3.45	1.80	5.05	1.28	1.53	3.14	6.16	8.72	5.50	14.50	5.19	1.46	58.53
1892..	0.20	1.24	1.70	0.02	1.27	17.55	5.03	5.76	9.24	11.91	2.25	1.53	58.20
1893..	4.21	0.26	0.56	1.12	5.79	10.67	4.64	7.13	3.15	13.31	4.14	5.56	60.59
1894..	0.46	1.26	2.42	0.78	2.60	6.78	5.11	2.40	10.26	13.53	4.17	0.94	50.71
1895..	0.45	5.05	1.21	1.85	4.22	3.76	4.22	4.05	13.57	12.47	2.16	1.23	55.85
1896..	1.11	6.22	3.69	0.00	2.70	16.91	3.10	3.26	5.73	1.47	3.53	2.73	51.06
1897..	6.31	1.23	3.22	5.67	0.33	5.26	5.26	5.73	7.61	3.13	1.45	0.30	46.21
Mean.	2.71	2.27	1.83	2.28	4.47	7.16	5.06	6.02	6.71	7.42	3.06	2.15	51.73

TABLE IV.—*Temperature and rainfall at Habana, Cuba—Continued.*

NUMBER OF DAYS ON WHICH RAIN FELL.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1863..	11	7	8	2	16	5	10	10	17	15	13	9	123
1864..	12	6	7	4	6	11	14	12	7	10	8	7	104
1865..	7	6	6	2	11	7	9	10	20	17	11	3	109
1866..	8	6	5	3	4	15	20	11	16	9	7	4	108
1867..	6	3	5	5	10	20	15	19	16	17	4	4	124
1868..	5	5	4	7	6	13	9	9	10	19	13	14	114
1869..	6	5	4	6	6	9	16	14	14	7	6	11	104
1870..	4	8	3	6	7	11	9	9	11	20	5	9	102
1871..	4	0	1	2	12	9	9	15	17	16	6	8	99
1872..	9	7	6	3	6	4	7	12	14	12	16	10	106
1873..	12	2	7	4	8	11	11	11	12	14	8	9	109
1874..	6	5	2	7	8	18	15	12	15	15	12	7	102
1875..	4	5	2	9	12	9	13	12	16	12	5	2	101
1876..	10	12	3	6	19	14	10	11	18	19	8	12	148
1877..	11	8	7	9	4	13	19	13	12	18	9	8	131
1878..	6	1	9	6	7	21	13	15	18	16	10	12	135
1879..	1	9	6	4	14	18	12	13	17	11	14	7	126
1880..	12	9	10	4	3	13	14	21	11	12	9	11	129
1881..	9	3	3	3	16	7	14	16	18	13	18	6	126
1882..	7	2	6	5	8	11	13	13	19	21	12	9	127
1883..	9	6	7	1	6	20	12	12	16	21	9	4	124
1884..	14	5	3	5	11	19	12	16	18	22	8	16	149
1885..	6	5	9	1	10	16	14	9	15	19	14	11	129
1886..	4	9	3	6	14	12	11	11	13	14	15	8	120
1887..	7	11	8	0	8	16	12	11	15	12	11	12	124
1887..	6	3	4	9	9	11	16	10	25	10	12	6	121
Mean	7.5	5.7	5.5	4.6	9.3	12.8	12.7	12.6	15.4	15.1	10.2	8.5	119.9

TABLE V.—*Temperature and rainfall at San Juan, Puerto Rico.*

MEAN MONTHLY TEMPERATURE.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1876..	79.0	78.1	79.5	81.7	84.6	84.0	84.4	83.8	83.1	82.9	81.1	80.4	82.4
1877..	79.0	78.1	79.5	81.7	84.6	84.0	84.4	83.8	83.1	82.9	81.1	80.4	82.4
1878..	79.3	81.0	81.0	82.0	84.6	86.0	85.6	85.6	84.6	84.0	81.9	79.9	82.9
1879..	78.6	78.2	78.8	80.8	81.7	83.7	84.9	83.8	81.0	79.3	77.4	73.8	80.2
1880..	78.4	72.3	74.8	73.4	79.2	81.1	81.7	82.4	82.0	81.3	80.2	77.7	78.2
1881..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1882..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1883..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1884..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1885..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1886..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1887..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1888..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1889..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1890..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1891..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1892..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1893..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1894..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1895..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1896..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
1897..	77.4	75.9	77.7	79.5	80.6	81.7	81.8	82.0	82.2	81.3	80.2	77.7	78.2
Mean	76.6	75.7	76.6	77.9	79.3	81.5	81.1	81.3	81.0	80.6	79.2	76.5	78.9

ABSOLUTE MAXIMUM TEMPERATURE.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1876..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1877..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1878..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1879..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1880..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1881..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1882..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1883..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1884..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1885..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1886..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1887..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1888..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1889..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1890..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1891..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1892..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1893..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1894..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1895..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1896..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
1897..	89.0	88.5	88.2	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3
Mean	88.5	87.8	90.0	95.0	98.1	95.4	95.0	95.4	94.8	97.9	90.1	83.5	90.3

TABLE V.—*Temperature and rainfall at San Juan, Puerto Rico—Continued.*

ABSOLUTE MINIMUM TEMPERATURE.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1876													
1877	69.1	66.7	68.0	72.0	72.7	72.7	74.1	74.5	73.4	73.0	72.3	70.5	.....
1878	69.4	70.2	70.9	71.6	73.8	75.2	71.6	76.3	74.8	75.2	71.2	68.8	.....
1879	65.5	64.8	69.1	70.9	70.9	72.7	72.3	72.3	75.2	72.3	72.7	69.1	.....
1880	64.8	63.0	66.2	67.3	69.4	66.2	69.1	71.6	69.1	69.8	68.0	64.8	.....
1881	65.1	64.4	64.8	66.2	69.1	72.0	66.9	67.3	70.5	70.9	70.2	66.6	.....
1884						70.9	70.5						.....
1888			62.6		66.6	71.2	73.0	69.8	72.3	71.6	69.8	63.7	62.6
1889	65.5	65.8	65.3					71.6	70.5	71.6	.....	66.6	65.3
1890	65.5		63.3		69.1								63.3
1891	65.1		63.7		67.6	64.8	70.9	70.2	69.8	69.8	67.3	62.2	63.7
1892	63.3	61.2	64.4	64.8	64.4	65.1	68.0	64.8	.....	61.2	59.4	63.1	.....
1893							64.0						
1894	57.2							64.0	64.9	62.2		57.9	57.2
1895	57.6	58.3	60.1	60.8	62.6	.....	65.3	65.5	65.1				

PRECIPITATION (in inches).

1876	.....	.....	.....	.....	.....	.....	.....	4.29	10.00	3.11	7.50	3.20	.....
1877	3.21	5.26	2.80	7.09	1.04	7.23	5.38	3.23	4.63	9.63	6.53	6.54	65.25
1878	2.75	1.59	12.40	4.10	10.26	8.17	11.55	5.53	5.23	11.92	4.84	2.02	32.64
1879	3.55	1.45	4.51	11.73	12.23	8.21	5.73	9.23	3.77	4.45	11.73	9.51	79.32
1880	2.59	1.93	0.51	1.61	8.23	5.45	5.23	5.59	3.23	1.97	6.34	2.25	45.79
1881	1.07	2.16	0.41	3.72	5.74	7.00	6.20	5.53	3.54	.....	.....	.....	.....
1884						4.43	2.23	.....	.....				.....
1888					3.58	5.53	2.45	6.23	7.73	4.64	3.40	5.51	43.61
1889	2.25	1.30	1.10					6.23	7.41	4.63	.....	4.50	32.13
1890	5.60		2.63		1.90								50.90
1891	1.33		0.29		4.91	4.23	4.51	17.07	4.00	8.51	10.90	4.23	64.63
1892	1.89	0.35	1.00	2.10	9.10	3.34	5.53	4.23		3.23	7.24	1.90	.....
1894								4.30					43.51
1895	2.23	0.70	1.39	7.37	6.43	.....	3.30	3.04	2.21	3.20	.....	5.23	.....
Mean	2.23	1.80	2.67	5.35	6.33	5.26	5.33	6.21	5.33	5.63	7.63	3.33	59.45

TABLE VI.—*Climatological data for several stations.*

WASHINGTON, D. C. (25 years).

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Temperature:													
Mean.....	33.2	35.8	41.3	53.0	63.9	73.2	76.3	74.6	67.3	56.2	44.5	36.2	54.7
Highest.....	76	78	83	93	98	102	103	101	104	92	80	73	104
Lowest.....	-14	-2	4	22	34	46	53	49	38	25	12	-13	-14
Rainfall:													
Mean.....	3.50	3.31	4.03	3.16	3.90	4.29	4.84	4.44	3.82	3.27	2.86	3.01	43.61
Greatest.....	7.09	6.84	8.84	9.13	10.69	8.55	10.63	12.93	10.81	8.69	7.18	4.94	61.33
Least.....	0.23	0.23	0.23	1.07	1.01	1.63	0.23	0.23	0.14	0.23	0.79	0.19	20.85
No. days on which rain fell:													
Average.....	12	11	12	11	12	11	11	12	9	9	10	11	129
Greatest.....	20	17	19	17	18	16	17	18	15	16	17	15	153
Least.....	4	4	5	7	5	5	8	5	2	3	5	5	113
Humidity:													
Mean relative, per cent.....	69	71	60	63	65	71	67	72	71	61	67	72	73
Mean absolute, grs. per cu. ft.	1.5	1.7	1.8	2.9	4.4	6.2	6.8	6.6	5.4	3.3	2.3	1.8	.....

NEW ORLEANS, LA. (25 years).

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Temperature:													
Mean.....	53.8	58.1	63.0	69.0	74.6	80.3	83.2	81.5	78.3	69.8	60.7	55.5	66.8
Highest.....	82	82	84	88	92	97	98	96	95	90	85	81	90
Lowest.....	15	25	30	33	38	53	67	63	58	40	30	20	15
Rainfall:													
Mean.....	5.17	4.56	5.35	5.26	4.76	6.49	6.50	6.02	4.70	3.35	4.30	4.36	60.52
Greatest.....	11.15	13.85	11.33	14.20	18.66	12.05	12.93	12.74	13.55	9.15	7.78	9.06	63.73
Least.....	0.66	0.04	0.29	0.23	0.23	2.71	3.02	0.87	0.25	T.	0.42	0.67	38.63

TABLE VI.—*Climatological data for several stations—Continued.*NEW ORLEANS, LA. (35 years)—*Continued.*

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
No. days on which rain fell:													
Average	11	10	9	8	9	14	16	14	11	7	9	11	138
Greatest	22	18	16	12	16	22	21	22	19	14	22	18	185
Least	5	2	5	2	3	5	10	7	2	0	4	2	100
Humidity:													
Mean relative, per cent.....	79	81	76	76	74	78	78	79	77	74	79	80	78
Mean absolute, grs. per cu. ft..	3.4	4.5	4.1	5.6	6.6	8.2	8.8	8.5	7.5	5.6	4.4	3.8	.....

HABANA, CUBA (10 years).

Temperature:													
Mean	70.8	72.0	73.2	76.1	78.8	81.5	83.4	82.2	80.7	78.1	75.3	71.4	76.8
Highest	84.4	87.6	91.4	93.6	99.0	97.7	100.6	98.6	96.6	91.9	89.7	86.0	100.6
Lowest	52.2	49.6	55.0	53.9	64.4	69.1	71.2	69.8	70.9	61.7	56.5	51.8	49.6
Rainfall:													
Mean	2.22	2.52	2.50	1.46	5.15	8.29	5.09	5.43	7.02	8.49	4.24	1.93	55.14
Greatest	6.51	6.18	5.06	5.67	17.51	17.56	7.12	9.36	13.57	13.53	7.94	5.56	60.06
Least	0.02	0.20	0.56	0.00	0.33	1.50	8.10	1.45	3.15	1.47	1.45	0.30	46.03
No. days on which rain fell:													
Mean	7.5	6.2	5.9	3.8	9.9	14.3	13.0	13.3	16.7	15.6	12.3	9.0	127.5
Greatest	14	11	10	9	16	20	16	21	23	22	18	16	149
Least	1	2	3	0	3	7	11	9	11	10	8	4	120
Humidity:													
Mean relative per cent.....	75	73	70	69	71	76	74	75	79	78	77	74	74
Mean absolute grs. per cu. ft..	6.2	6.4	6.3	6.8	7.6	8.7	8.8	8.8	8.9	8.1	7.4	6.8	7.5
Wind:													
Average velocity, miles per hour.	7.8	8.3	8.7	9.2	7.8	6.7	6.5	6.3	6.5	7.8	8.7	8.3	7.8
Prevailing direction.....	e.	e.	e.	e.	e.	e.	e.	e.	e.	n., e.	e.	e.	e.

MINES OF SAN FERNANDO, CUBA (1 year).

Temperature:													
Mean	69.9	71.4	73.2	74.6	77.9	78.9	80.5	79.6	78.6	75.9	72.7	67.9	75.0
Highest	79	78	82	83	85	85	86	87	86	81	80	77	87
Lowest	57	57	62	64	71	73	71	71	68	70	65	51	57
Rainfall:													
Total	2.74	0.50	2.49	2.09	20.28	14.56	...	...	...	...	...	...	...
Maximum in any shower.....	1.20	0.20	1.13	1.35	7.30	2.50	...	...	...	...	...	...	...
No. days on which rain fell..	4	2	7	7	21	17	22	20	16	22	2	6	.....

KINGSTON, JAMAICA (10 years).

Temperature:													
Mean	74.6	74.7	75.8	77.9	79.4	80.8	81.1	80.4	80.1	78.9	77.8	75.7	78.1
Highest *	82.4	85.8	85.7	85.5	87.2	88.5	89.7	89.4	89.7	88.9	86.9	87.0	89.7
Lowest *	66.8	66.8	67.8	69.9	72.4	73.8	73.5	73.2	73.2	72.1	70.7	68.4	66.8
Humidity:													
Mean relative, per cent.....	78	78	77	75	73	73	73	79	80	81	78	73	73
Mean absolute, grs. per cu. ft..	7.2	7.2	7.4	7.7	8.4	8.7	8.6	8.8	8.8	8.6	8.0	7.5	8.0
Rainfall:													
Mean	0.96	0.23	1.59	1.02	6.00	5.51	3.15	4.09	3.59	4.69	1.22	1.50	32.64

SAN JUAN, PUERTO RICO (12 years).

Temperature:													
Mean	76.6	75.7	76.6	77.9	79.3	81.5	81.1	81.3	81.0	80.6	79.2	76.5	78.9
Highest	92.2	92.5	95.4	95.0	100.8	99.3	96.8	99.0	96.8	97.9	99.1	92.5	100.8
Lowest	57.2	58.3	60.1	60.8	62.6	64.8	64.0	64.0	64.9	61.2	59.4	56.1	56.1
Rainfall:													
Mean	2.23	1.80	2.67	5.35	6.33	5.96	5.82	6.21	5.83	5.63	7.62	3.93	52.45
Greatest	8.60	5.36	12.40	11.78	12.25	8.91	11.56	17.07	10.00	11.93	11.73	6.34	53.64
Least	1.07	0.35	0.29	1.61	1.90	2.34	2.48	3.04	2.91	1.97	3.40	1.90	45.79

* Probably the averages of the extremes.

TABLE VII.—Average number of rainy days at several places in the United States.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Key West *.....	8.1	6.8	4.9	4.5	8.5	11.8	12.6	14.6	16.4	12.4	8.0	7.2	117.7
Jacksonville†.....	9.5	9.1	8.2	6.7	9.8	12.5	15.0	15.0	14.1	9.0	8.0	7.2	124.9
New Orleans†.....	11.2	9.4	9.8	7.9	9.9	12.6	15.3	14.4	10.8	7.4	9.4	11.9	131.7
Charleston*.....	10.6	10.1	10.0	7.7	9.1	10.9	12.1	13.3	10.6	7.4	7.7	8.9	115.5
Washington*.....	12.1	10.9	12.2	11.2	12.2	10.5	11.1	11.3	8.6	8.8	10.1	10.4	129.2
New York ‡.....	11.9	10.9	11.8	11.1	10.4	10.4	11.2	9.8	9.3	9.6	10.2	11.0	127.8
Boston*.....	12.8	11.1	12.8	11.4	11.2	10.3	11.0	10.4	9.6	10.0	11.1	11.7	123.0
Chicago*.....	11.8	10.8	12.0	11.4	11.8	11.4	9.2	9.0	9.0	10.1	11.0	12.1	131.1
St. Louis*.....	9.1	9.5	10.8	10.3	11.8	11.4	9.6	7.6	7.0	7.3	9.1	9.9	113.3
San Francisco*..	11.4	10.6	10.8	7.4	4.2	2.0	0.6	0.3	1.6	3.8	6.4	11.2	69.4

* Record for 25 years.

† Record for 24 years.

‡ Record for 18 years.

TABLE VIII.—Location of stations from which meteorological data are quoted.

Place.	Lat. N.	Long. W.	Height above sea.	Place.	Lat. N.	Long. W.	Height above sea.
	°	'	Feet.		°	'	Feet.
Key West, Fla.....	24	34	81 49	San Juan, Porto Rico....	18	37	65 39
Nassau, N. P.....	26	5	77 21	St. Thomas.....	18	31	64 55
Habana, Cuba.....	23	9	82 23	Ft. de France, Martinique..	14	40	61 2
Matanzas, Cuba.....	23	3	81 40	St. Pierre, Martinique....	14	46	61 7
Mines of San Fernando..	23	22	80 9	Kingstown, St. Vincent....	12	12	61 13
Santiago, Cuba.....	19	55	75 50	Bayabou, St. Vincent.....	12	12	61 11
Ubayay, Cuba.....	*	*	943	Barbados.....	13	4	59 57
Denbigh, Jamaica.....				Royal Botanical Gardens,			
Kingston, Jamaica.....	17	56	75 48	Trinidad.....	10	40	61 36
Ross View, Jamaica.....	18	3	75 44	Merida, Yucatan.....	20	58	39 3
Port au Prince, Haiti....	18	32	72 21				

* About 15 miles southwest of Habana.

WEATHER OF MANILA.

Manila, the capital and chief port of the Philippine Islands, is situated in latitude $14^{\circ} 35'$ north, and in longitude 121° east of Greenwich.

Meteorological observations have been made for many years at the Observatorio Meteorologico de Manila. Observations of rainfall for thirty-two consecutive years, and of the other meteorological elements for seventeen consecutive years have been published by the Observatory. The appended table, compiled by Prof. H. A. Hazen, of the Weather Bureau, gives in a concise form the more important meteorological elements of the climate.

Temperature.—The average temperature of the year is 80° F. The months of April, May, and June are the hottest part of the year. May, with an average temperature of 84° F., is the hottest of the three. December and January are the coolest months, each with an average temperature of 77° F. The highest thermometer reading recorded is 100° F; this was observed in May. The lowest reading recorded is 74° , and was observed in January.

Humidity.—The average relative humidity is 78 per cent. That of the most humid month, which is September, is 85 per cent, and that of the least humid month, which is April, is 70 per cent. The average absolute humidity is 8.75 grains in a cubic foot. It is greatest in August and least in February.

Rainfall.—The average annual rainfall is 75.43 inches, of which 43.69 inches, more than 57 per cent, fall during the months of July, August, and September, and 50.74 inches, more than 80 per cent, fall from June to October, inclusive. September has the largest average fall, 15.01 inches, and February the smallest average fall, 0.47 inches. The heaviest rainfall in any one month was 61.43 inches, in September, and sometimes no rain at all has fallen in February, March, April, and May.

Departures from the average rainfall are in some instances remarkable. For example, as much as 120.98 inches have fallen in one year, and as little as 35.65 inches in another. Still more remarkable was the fall of 61.43 inches in one September, and that of only 2.00 inches in another September.

TABLE IX.—*Temperature, rainfall, etc., at Manila.*

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Temperature (degrees F):													
Mean monthly.....	77	78	81	83	84	85	81	81	81	80	79	77	80
Warmest month.....	79	81	82	85	87	88	88	88	88	88	81	80	88
Coollest month.....	74	78	79	81	82	81	79	80	79	79	77	75	79
Highest.....	91	96	98	99	100	98	98	94	94	95	94	92	100
Lowest.....	60	61	65	66	71	70	70	69	71	68	68	60	60
Humidity:													
Relative, per cent.....	77	73	71	70	75	80	84	84	85	82	80	80	78
Absolute, grains per cu. ft.	7.75	7.60	7.90	8.42	9.27	9.39	9.33	9.53	9.33	9.34	8.59	8.06	8.75
Wind movement in miles:													
Daily mean.....	98	115	132	145	144	138	133	165	192	111	94	98	124
Greatest daily.....	153	187	230	239	236	261	267	254	282	196	164	153	204
Least daily.....	68	72	82	92	68	96	110	79	69	48	67	59	96
Prevailing wind direction....	ne.	e.	e.	se.	se.	se.	sw.	sw.	sw.	ne.	ne.	ne.	.....
Cloudiness, per cent.....	45	37	35	32	47	65	74	68	72	58	54	53	53
Days with rain.....	4.3	2.2	3.4	3.5	9.2	15.4	22.1	19.8	20.7	14.4	11.3	8.4	135
Rainfall in inches:													
Mean monthly.....	1.15	0.47	0.65	1.11	4.30	9.68	14.70	13.88	15.01	7.47	4.92	2.09	75.43
Greatest monthly.....	7.59	1.97	3.94	5.37	10.11	25.81	39.71	43.20	61.43	23.65	15.27	13.67	120.98
Least monthly.....	0.02	0.00	0.00	0.00	0.00	0.98	5.28	5.15	2.00	0.90	1.17	0.01	35.65

Rainfall record for 22 years, 1865-1886; remaining data for 17 years, 1880-1896.

Bulletin No. 23.—W. B. No. 186.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

FROST:

WHEN TO EXPECT IT AND HOW TO LESSEN THE
INJURY THEREFROM.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau.

BY

W. H. HAMMON,

PROFESSOR OF METEOROLOGY.



WASHINGTON:
WEATHER BUREAU,
1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., November 10, 1898.

Hon. JAMES WILSON,
Secretary of Agriculture, Washington, D. C.:

DEAR SIR: I have the honor to transmit herewith a paper on the subject of frost, prepared by Mr. W. H. Hammon, forecast official, San Francisco, Cal., with request that it be printed as a bulletin of the Weather Bureau.

Mr. Hammon has devoted much thought to and made careful study and investigation of this subject. The paper is a revision of one formerly prepared by him and issued as a bulletin of the Weather Bureau. It was received with much favor, having been published by the California State Board of Horticulture. The urgent demands for a reprint that have been received have prompted a revision of the pamphlet, with a view to republication. An edition of five thousand is recommended.

I am, very respectfully,

WILLIS L. MOORE,
Chief of Weather Bureau.

Approved.

JAMES WILSON,
Secretary.

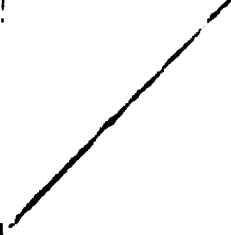


TABLE OF CONTENTS.

	Page.
Preface	7
Formation of frost	9
Methods of frost prevention.....	10
Methods for retarding radiation.....	11
Raising the dew-point.....	14
Portable smudge fires.....	15
Steam and vapor protection.....	18
Adding heat to the air.....	20
Directly heating the air by means of fires.....	21
Report of experiments in frost protection made by the Riverside Horti- cultural Club.....	22
Orchard protection.....	27
Draining cold air from region needing protection.....	28
Mixing air so as to prevent cold air from sinking to the surface.....	29
Appendix No. 1.	
Use of the sling psychrometer.....	34
Dew-point table.....	36
Appendix No. 2.	
Injurious temperatures.....	37

PREFACE.

In December, 1895, a freeze occurred in the citrus region of southern California which very appreciably reduced the orange output for that season. The temperatures, even in the coldest localities, were so little below the point of safety that it seemed as if the loss might have been avoided had the orchardists been familiar with the principles of frost protection. With the purpose of furnishing this information the writer prepared, in January, 1896, a short article on frost protection, which was published by the Department of Agriculture in Weather Bureau Bulletin No. 86.

Since the publication of this bulletin the subject of frost protection has received much attention, especially in California. Many orchardists made experiments along the line suggested in this bulletin. The agricultural and even the daily press gave liberal space to the discussion of these subjects. Many devices and methods were proposed and some were tested. So much was accomplished in the spring of 1896 that the California State Board of Horticulture deemed it advisable to publish a more extensive bulletin than Weather Bureau Bulletin No. 86, embodying these experiments and suggestions. This was accomplished in Bulletin No. 70 of that society, published in the autumn of 1896, probably the most complete bulletin written on this subject that had then been published in this country.

However, experiments, made since the publication of this pamphlet, render a modification of many of its statements necessary. Too great prominence was given to certain methods and too little to others. Important exceptions have been found to some general rules. Consequently it has been deemed advisable to publish a revised edition of this bulletin, incorporating in it the lessons gained from more recent experiments.

While the methods advocated are mainly the result of experiments conducted in California orchards, still the principles are capable of much broader application, and the rules laid down for protecting these orchards will prove generally useful with such modifications as local topography and atmospheric conditions may render advisable.



FORMATION OF FROST

Before proceeding to a consideration of methods of preventing injury by frost, it is essential that the conditions under which it forms be quite thoroughly understood.

The two principal methods by which plants lose their heat are *convection* and *radiation*.

The movement of the air is continuously bringing new particles of it in contact with the plants, and if the air be cooler than the plants it will take from the plants a portion of their heat, until both air and plants are at the same temperature. This is known as *convection*, and is very effective on windy nights when a cold wave is approaching, and the breeze is continually bringing new portions of the atmosphere about the plants. We can hardly attribute to this process the great loss of heat on the quiet, clear nights when frosts mostly occur; for on such nights the plants are usually colder than the surrounding air, and any mixing of the air tends to raise their temperature.

The chief method by which plants lose their heat on calm, frosty nights is by *radiation*. By this term is meant that peculiar process by which heat escapes from an object and passes through the surrounding space in direct lines in the same way that rays are emitted from a source of light. Heat, lost by radiation, does not appreciably warm the air through which the ray passes, but its effects are manifest at any surface which obstructs the passage of the ray.

The surface of the earth is continually losing heat by radiation into space, but during the day it usually receives heat from the sun more rapidly than it loses it by radiation, and consequently it grows warmer. At night, however, heat from this source is cut off and the continued radiation causes the temperature to fall.

Under favorable conditions this fall continues until condensation of vapor begins. Aqueous vapor, although invisible, is always present in greater or less quantities in our atmosphere, and can always be condensed into water if the temperature be sufficiently lowered. If the condensation takes place at temperatures below the freezing point of water, the moisture is deposited in the form of frost.

The heat given off by the condensation of vapor is enormous. The condensation of enough vapor to make a pint of water will evolve enough heat to raise more than five pints of water from the freezing to the boiling point. All this heat must be lost by radiation in order that the formation of dew may proceed or the temperature fall. It is, therefore, evident that when condensation begins, the heat evolved by this means practically prevents further cooling.

The temperature at which condensation begins is called the "dew-point," and varies with the amount of moisture in the air, being higher the greater the amount of moisture present. It is always constant for the same amount of vapor.

Radiation takes place most rapidly when there is nothing to obscure the sky. Clouds or any other obstruction act as a screen in retarding it. Even water vapor, while invisible, has a very appreciable effect in retarding it. It takes place more rapidly from the surface of plants than it does from the air about them, so that on still nights these surfaces are frequently cooled several degrees below the temperature of the surrounding air.

One more principle should be considered in the study of the conditions under which frost forms, and that is the increased density of the air as its temperature is lowered. Owing to this principle, the air, on calm nights, arranges itself in accordance with its density. The heavier cold air rests on the surface and surrounds the plants and trees, thus increasing their liability to injury. On still nights this fact is often very manifest. Frequently a thermometer close to the ground will read 5° or 10° lower than one 8 or 10 feet higher. This principle causes the air on slopes, as it becomes chilled by radiation, to flow down into the valleys, where it accumulates, thus frequently causing severe frosts in the lowlands, while the hillsides remain uninjured. It is for this reason that frost does not so readily occur on windy nights, since the wind mixes the air to a more uniform temperature throughout and causes that near the ground to be warmer than it would be otherwise.

Therefore, the conditions favorable to frost formation are: (1) Clear sky, because radiation of heat is rapid under these conditions; (2) dry air, because with dry air, cooling by radiation will continue to a lower temperature before it is checked by the heat given off by condensation; (3) still nights, because under these circumstances the air arranges itself in layers according to its density, and the colder, denser air collects near the surface.

METHODS OF FROST PREVENTION.

From a study of the foregoing principles under which frost forms, it would seem that there would be the greatest probability of success in preventing frost or diminishing its severity by working along the following lines:

I. Diminishing the radiation of heat.

II. Raising the dew-point by adding moisture to the air, and thus making sensible the latent heat of condensation at a temperature above the danger point.

III. Adding heat to the air.

IV. Draining the cold air away from the section which requires protection.

V. Mixing the air so as to prevent the cold air from sinking to the surface.

It is believed that all efficient methods of protection which have been devised are embraced under one or more of these classes. The methods will be grouped in accordance with the above classification

I. METHOD FOR RETARDING RADIATION.

Since radiant heat is transmitted in straight lines, the erection of any screen between the plants and the open sky tends to intercept the rays and either reflect them back toward the earth or absorb them, thus raising the temperature of the screen which checks the loss of heat, for the screen itself now becomes a radiating surface and returns a portion of its heat to the earth.

Any substance which tends to obstruct the passage of heat rays forms a more or less effective screen for checking radiation.

Glass screens.—In greenhouses and hotbeds advantage is taken of the peculiar property of glass which allows the heat rays of the sun to pass through it, and is almost impervious to the dark heat rays from the earth and plants. This is one of the most perfect screens possible, since it not only prevents the loss of heat by radiation, but receives and retains the heat from the sun. The expense precludes its adoption, except for the protection of valuable plants and flowers.

Screens of other solid materials have been quite extensively used in protecting vineyards and citrus groves where intense cultivation is practiced, and where the location of the groves, near an excellent market, admits of profit even with expensive methods of cultivation.

Cloth screens.—In Italy and portions of France screens made of muslin strung on wires stretched on poles above the tops of trees or vines have been used extensively. These screens are drawn on nights when frosts are probable and pushed back during the day. When the season has advanced so as to preclude further danger, they are taken down and stored. Of course, such a plan could be operated only on a very limited scale, and would then be expensive. This plan has been recently successfully tried in the orange groves of southern California.

Lath screens.—During the past few years screens made of laths fastened to ordinary telephone wire (the spaces between them being about the width of the laths) have been extensively used in Florida. These are spread over a frame erected above the trees or plants. The screens serve not only as a fair protection from frost, but also as a shade from hot sun. When no longer needed they can be rolled up and stored away for preservation. At first thought it would seem improbable that a screen covering only half the space (the spaces

being as wide as the laths) would afford much protection; but, when it is considered that laths have considerable thickness, it is plain that, while only one-half the vertical rays are screened, those inclined between the vertical and horizontal are partially intercepted by the edges as well as the faces of the laths. As a matter of fact, about three-fourths of the sky is screened by this means.

By placing the laths in north and south directions, the direct rays of the morning sun are completely cut off from the orchard, which admits of the temperature rising slowly. This greatly reduces the liability of injury to the plants. Dr. B. T. Galloway, in the U. S. Department of Agriculture Yearbook, 1895 (p. 145), thus explains why frozen plants are less likely to be injured when warmed slowly:

Under the influence of cold, the water in the cells escapes, and may be frozen either in the spaces between the cells or on the surface of the leaf, stem, or whatever the part may be. As the temperature rises, this frozen water may again be taken up by the cells, and in such cases little or no injury results. If for any reason, however, the cells are not able to regain the water withdrawn by the cold, injury or even death may result. In many cases the rapidity with which the ice is thawed has a marked effect on the ability of the cells to gain their normal condition. If the thaw is gradual, the water is furnished no faster than the cells can absorb it, and equilibrium is, therefore, soon restored, the chemical processes which were checked during the freeze are resumed, and the plant soon regains its normal condition. With a rapid thaw, however, the cells are not able to take up the water as fast as it is furnished, and as a result chemical decomposition sets in, and death follows. Death in this case is essentially the same as that which results from drought. The cell loses water to such an extent that it is not again able to become turgid, and as a result it finally withers and dies.

Other methods.—While the foregoing methods are quite efficacious in preventing injury, still the expense is entirely too great to admit of their adoption for general use in orchards.

Strawberries and other low plants are frequently protected by covering them with straw or other loose substances.

Frequently young potato plants are saved by plowing a furrow alongside and allowing the dirt to bury them.

Cranberry growers in the marshes of Wisconsin flood the marshes when frost is expected. In this case the protection is probably due, for the most part, to the high specific heat of water, as only portions of this land are submerged.

Smudge fires.—Since radiation is so reduced as to prevent the formation of frost on cloudy nights, many have thought that an artificial obscuration of the sky by means of dense smoke would be an excellent means of protection. The efforts of this character which have been made have resulted in decidedly varying success. In the wheat fields of the Dakotas, excellent protection was obtained, while the experience of orchardists in Florida and southern California has not shown such a uniform success.

Since it was supposed that the protection resulted from the obscuration of the sky by means of smoke, the best protection was expected from the use of that fuel which would produce the greatest smoke.

In the Dakotas the best and most convenient material at hand was the straw of the previous year's crop, which had been left in the fields all the winter and through the rainy spring, until it was quite thoroughly soaked with water.

In southern California and Florida straw was scarce, and where it could be obtained it was much drier than that used in the Dakotas, consequently tar, crude petroleum, and other similar smudge materials were substituted; but the results have not been, as a rule, satisfactory, although the smoke was equally dense. However, quite successful results were obtained by Mr. Buck, Mr. La Rue, and others in the Vacaville and Sonoma sections by burning damp stable manure in sacks scattered through the orchard.

After considering the question, the writer was convinced that the protection of the northern wheat fields must be due to something besides the checking of radiation by the cloud of smoke, for the heat which is radiated from the earth to the cloud is absorbed by the cloud and not reflected. Consequently, unless the air is almost perfectly calm to a considerable elevation, the heat is carried away as the smoke drifts off with the wind before much is radiated by the cloud of smoke back to the earth.

Damp smudge fuel preferable.—It was observed that, as a rule, whenever damp fuel was used, the efforts at protecting were more successful than at other times. In the case of dry smudge material, the heat of the fire raises the temperature of the air about the burning fuel to hundreds of degrees above the surrounding air. It is consequently greatly expanded, and its density diminished so that it rapidly rises and the neighboring air flows in to take its place. This also is, in turn, heated and escapes upward, carrying the heat and smoke of the fire with it. On reaching an elevation considerably above the trees, it is blown away more or less rapidly by the almost constant circulation of air at such an elevation.

When damp fuel is used, a considerable portion of the heat of the fire is expended in evaporating the water in the fuel, and the consequent upward draft of the fire is lessened by this amount.

The amount of heat consumed in evaporating water is very considerable. The evaporation of a quart of water would necessitate the expenditure of as much energy as would be needed in raising the temperature of the air 25° throughout a space 10 feet square and deep.

It is evident from this fact that the upward draft, which was so marked in the case of dry fuel, is greatly diminished when damp fuel

is used; consequently, the smoke remains nearer the surface, where the trees interfere with the movement of the wind and tend to retain the smoke, thus increasing the protection.

Further, Tyndall has proven that vapor itself, even while invisible acts as a barrier in retarding radiation, and if it condense rapidly enough it will cause the small particles of water thus left suspended in the air to form a cloud or fog, which will obscure the sky and prevent radiation.

However, by far the principal cause of the protection obtained from the wet smudge properly belongs to the second class of methods namely:

II. RAISING THE DEW-POINT.

By adding moisture to the air and thus making sensible the latent heat of condensation at a temperature above the danger point.—As mentioned above, when damp fuel is used a considerable portion of the heat produced by the fire is expended in evaporating the water in the fuel. The vapor thus formed is invisible and has all the properties of a gas, and quickly distributes itself throughout the surrounding space almost as rapidly as air will expand to fill a vacuum, for it is a property of gases that each will occupy a given space in almost the same manner as it would if the others were not present. But as the vapor expands into the surrounding cooler air its temperature is lowered and, unless the air be very dry, a portion of the vapor is condensed, forming a visible fog or mist. Now, all the heat which was consumed in evaporating the water again becomes sensible upon its condensation, and tends to raise the temperature of the surrounding air. The heat thus set free will be in great part confined to the particles of water composing the fog, which are too dense to rise, and thus they will tend to prevent the escape of the heat, and at the same time they are so small that they float in the air as fog, with hardly a perceptible tendency to fall.

The tendency is, therefore, to trap the heat produced by the fire and distribute it throughout the space near the surface which needs protection. The excessive heat about the fire which, with dry fuel, produces the wasteful upward draft, is, in this instance, utilized in evaporating the water in the fuel. The vapor then, by the operation of its gaseous property, distributes itself quickly throughout the surrounding cooler space, where, in condensing, it sets free its latent heat, warming the region, and, by the density of the fine particles of water thus warmed, the heat is retained near the surface.

After a considerable study of various methods of protecting orchards against frost which have thus far been made public, the writer has become convinced that those which depend for their success upon this principle (II) are generally the most efficient. In very dry climates, however, where the dew-point at times of danger

is 10° or more below the temperature of the air, this method is inefficient since the vapor does not condense in sufficient quantities to protect, and owing to the vapor being lighter than air, it escapes upward and the heat necessary for its formation is lost.

Many methods which involve this principle have been suggested and tried, two of which have already been mentioned, namely:

Fires of damp straw and stable manure.—Have the fuel, in small piles, distributed throughout the orchard in advance; the more numerous the piles the better. With the same amount of fuel the best protection is obtained from small and frequent fires, since, with small fires, the upward draft is reduced to a minimum, and the more frequent the fires the more uniform will be the distribution of heat.

Sacks of manure.—A decidedly preferable method is to pack damp stable manure in common grain or burlap sacks, by which it can be conveniently handled. They should be distributed through the orchards in rows about 100 feet apart, and about 50 feet between sacks in each row. When it is found necessary to protect, a small amount of coal-oil is poured upon each sack and ignited. It is usually unnecessary to fire more than every second or fourth sack, the remainder being left for later occasions. These sacks will burn with a smoldering fire for several hours.

The amount of heat which is set free by burning one sack of manure weighing about 50 pounds, and condensing the vapor near the surface, would be sufficient to raise the temperature 20° in a space 75 feet square and 25 feet deep. If one-fourth of this heat remained within the region needing protection, which seems to be a reasonable estimate, ample protection would be obtained for almost any ordinary conditions.

Bales of wet straw.—Mr. T. A. Morrison, of Riverside, Cal., suggested the use of a similar plan, in which bales of wet straw were substituted for manure. This plan has been tried with fair success. One-hundred pound bales were cut in four pieces, a tie wire being left about each piece, and, if properly dampened, will burn with but little care, causing a small smoldering fire.

Prunings.—The prunings of the trees, which are usually removed shortly before the period when frosts are likely to do their greatest injury, are excellent smudge material, and should always be preserved for this use. They should be piled in open spaces throughout the orchard or vineyard, and burned at times when protection may be needed. The best results will be obtained from as small fires as will result in burning the prunings.

PORTABLE SMUDGE FIRES.

A number of excellent devices have been tried, in which the fires

were built upon some vehicle by which they could be moved about the orchard. The advantages of this plan are several:

First. The fire can be moved to the section where most needed, generally along the windward side of the orchard.

Second. The loss of heat by an upward draft is almost entirely prevented, since the fire does not remain in one position long enough to establish such a draft. On this account, much larger and, consequently, fewer fires, with equal efficiency, are possible.

Third. There is a much more uniform distribution of heat throughout the orchard.

The Fleming Fruit Company's process.—One of the first to adopt this plan was the Fleming Fruit Company, of Visalia, Cal., the manager of which thus describes his method:

We built wire frames (chicken-yard fencing) on our low truck wagons, stretching them from four wagon stakes and heaping over with wet manure. Dirt was then thrown on the wagon beds to protect them, and pots of burning tar were set underneath the straw roof. A barrel of water on the wagon was used to keep the straw wet. These wagons were driven about and did the best work, as they could go wherever most needed. The smoke and vapor were carried to the rear as the wagon moved, and, being carried at once out of the rising heat, fell close to the ground in a long, white trail. At daylight our whole 400 acres of orchard were covered with a white fog, extending from the ground to about 20 feet high.

They also used similar fires as stationary smudges, the wire netting being stretched between four stakes driven in the ground, and a similar plan has been since experimented with by Meacham Brothers, of Riverside, Cal. These latter proved much less efficient.

The plan of the Rio Benito Orchard Company.—A modified form of the Fleming process was used with excellent results by this company at Biggs, Cal. In this case rough sleds were constructed at a cost of less than \$2 each. The runners were of 2 by 4 scantling, which were connected by a few boards about 4 feet long. Upon these dirt was piled to hold the pot of burning tar. The four upright sticks were spiked to the runners, the tops of which, about 13 inches above the bed of the sled, were connected by strips of inch boards 4 to 6 inches wide. To these strips the chicken-wire netting was attached. This rude box or screen supported the wet straw or manure used as smudge material. Four of these sleds, two wagons rigged after the Fleming plan, and about 500 sacks of manure were found sufficient protection for an orchard of 300 acres during each night of the severe April frost of 1896. The orchard was successfully protected during six successive nights of severe frost, at an expense of less than 1 per cent of the value of the crop undoubtedly saved by this means.

This device can be made much more efficient by supporting the center of the screen by an arch of heavy, stiff wire passing diagonally from runner to runner and forcing up the bottom of the screen so as to cause it to present a concave surface to the fire, thus causing more

of the heat to pass through the smudge material and less to escape upward about the sides of the screen.

Mr. Priestly Hall's device.—Mr. Priestly Hall has made a much more efficient form of sled, operating under the same principle. Upon a sheet-iron bed of a sled he has placed a small fire-box, consisting of a grate 4 or 5 inches above the bed of the sled, over which pass iron rods bent in the form of an arch, leaving a space for the fire about 14 inches in diameter. This fire-box is inclosed in a large corrugated iron box, which has the bed of the sled (about 3 by 4 feet in size) for a bottom, and sides 30 inches high. A door is made in the front of the corrugated box, to admit fuel to the fire. The box is kept filled with wet straw or manure and a fire is maintained in the fire-box when the machine is in operation.

The Howard method.—Mr. R. H. Howard, of Riverside, Cal., has devised a somewhat similar plan, which undoubtedly will be found very efficient. The fuel used is crude petroleum, supplied to the burner from a tank on the wagon or truck containing the apparatus. Over the burner is placed a large wire basket, containing mineral wool, which is kept saturated with water supplied by a tank, also placed upon the wagon. Wet straw or manure could also be used, if desired. The apparatus can be driven about the orchard where most needed. The burning coal-oil gives off a dense smoke, while the wet mineral wool will furnish a vast amount of surface from which evaporation can take place, and at the same time the material will not be consumed. Mr. Howard suggests the use of somewhat similar devices for stationary evaporators placed in various portions of the orchard.

Mr. George F. Ditzler's machine.—A number of more or less expensive mechanical appliances have been devised which depend upon this principle (II) for their success in protecting. Undoubtedly, among the best of these should be mentioned that of Mr. George F. Ditzler, superintendent of the Rio Benito orchards at Biggs, Cal. The machine consists of a large sheet-iron tank, 3 or 4 feet square and deep, which is mounted upon a truck. About 6 inches from the bottom of the tank a wire screen or grate is erected. Through a hole in the tank beneath the screen a blast is admitted, which is produced by a revolving fan similar to those used in blacksmith forges. This is operated by a sprocket chain and wheel attached to the wheel of the truck. A water cask and force pump, operated by the movement of the wagon, complete the outfit. In operation, a little tar or other fuel is placed upon the grate and ignited, and the tank is then filled with wet straw or manure, when the machine is put in motion. The blast thus produced causes an intense fire, which will burn the wettest of fuel, and all of the heat of the fire must pass up through the 3 feet of wet material before it can escape into the air. By this means, almost the entire heat is consumed in evaporating water, which

quickly condenses after escaping from the tank, and forms a dense fog or mist. That the heat of the fire is thus expended in evaporating water is evidenced by the fact that the air which escapes from the tank, charged with moisture, is but little warmer than the surrounding atmosphere. While the machine is in motion, water is continually pumped from the cask and discharged from small holes about the top of the tank upon the fuel. The machine is driven forward and back between the rows of trees in the orchard. It is said that one such machine will evaporate 100 gallons per hour, which, under the conditions it produces, should protect about 50 acres. The fog thus formed in the orchard is so dense that the driver frequently has to go ahead and lead the team, since, from the truck, he can not see to drive it.

Probably no greater protection has been obtained from the burning of the same amount of fuel than by this machine, since but little, if any, of the heat is wasted; however, it may be a question if the gain over that obtained from the use of other portable smudges is sufficient to warrant the increased expense for constructing these machines.

STEAM AND VAPOR PROTECTION.

Many devices have been suggested for protecting by the addition of moisture to the air, besides those involving the wet smudge. A number of these have proven efficient. It would seem, however, as if these plans were not likely to be quite as efficient as the wet smudge, since, with equal evaporation, the wet smudge has the additional protection obtained from retarding the radiation of heat by means of the screen of smoke.

Mr. H. C. Finkle's plan.—Mr. H. C. Finkle, a civil engineer of San Bernardino, Cal., outlined in the *Riverside Press*, in February, 1896, quite an elaborate plan for protecting citrus groves in southern California. The essential feature of the plan provided for the erection of several large plants for evaporating water from pans over coal-oil furnaces.

The criticism most likely to be made of this plan will be that the upward draft, which must exist with all large stationary fires, will cause a large portion of the heat and the vapor to be carried above the region needing protection.

Further, it is very doubtful if any evaporating pan which might be used would evaporate as much water as would result from the burning of wet straw over the same fire, for the hot gases and air from the fire come in contact with vastly greater surfaces in filtering through the mass of straw than will be encountered in the best of evaporators. The straws thus act as the tubes in a boiler in increasing the surface exposed to the heat.

Such a plant placed at the lowest point in a valley, however, might

be of use in assisting to dissipate the cold air that accumulates in such places, by drawing it into the fire; but in this case a steam-boiler would be preferable, from which the steam might be conducted in pipes for a considerable distance underneath the trees and then allowed to escape from small vents or jets scattered along the pipes.

The evaporating pans previously described were proven inefficient in the extensive experiments conducted at Riverside, Cal., during the winter of 1897-98.

In the preceding methods, heat has been used to add moisture to the air, but several very successful plans do not require that agency. The two most important methods are—

Spraying and irrigating.—By spraying plants and trees with a very fine spray in times of frost, the injury will, in most instances, be greatly diminished. At the Everest Ranch, Riverside, Cal., a portion of the orange grove is protected by sprinklers placed at the top of 50-foot masts, which fill the air with a very fine spray. In nearly every instance the protection has been sufficient, but at times of very severe freezes the accumulation of ice on the trees bruises the tender branches.

Sprinkling a garden before sunrise on a frosty morning has proven of decided value. The water remains on the plants, and is available for absorption by the burst cells of frozen plants as they thaw, and the injury is thus reduced.

In regard to the value of irrigation, Mr. I. H. Thomas, of Visalia, Cal., thus writes to the California State Board of Trade:

I turned the water on my place a few days before the freeze, and I found it to be a safe remedy against damage by frost. Wherever the water was run, the effect of the frost was neutralized, and the fruit was not damaged. By reason of this precaution I will have a good crop of fruit, while some of my neighbors, who resorted to smudging, lost almost their entire crop. This proves one thing of great value and importance to the fruit-growing industry: that by wetting the soil during these periods of freezing, and causing an evaporation of moisture tempered by the warmth of the soil, the frost is neutralized, and damage averted.

In my orchard, where the thermometer fell as low as 23°, this process resulted in saving my crop from material damage. As a further evidence of a proof of this theory, the Visalia Fruit and Land Company's orchard on St. John's River, for thirty or forty rows nearest the river, as far from the banks as the seepage was sufficient to cause an evaporation of moisture, the fruit was not materially damaged, while back of that, where there was no seepage and where the land was perfectly dry, the crop was ruined.

At another orchard, where they smudged during the frosty period and at great expense, and kept up a cloud of smoke so dense that you could hardly see from one row to another, the damage almost annihilated the crop, except in the case of 40 acres where the water had been turned on a few days before the freeze. On this 40 acres but very little damage resulted. In one spot on the 40 acres that was flooded there was a piece of raised ground that contained 20 or 30 trees, and which the water did not reach. The fruit on the trees of this spot was killed, while, as soon as you came to the trees on the flooded portion, there was no perceptible damage.

This tells a great story, and is not only an additional argument in favor of irrigation in general, but it enjoins the fruit-grower to have his water available early in the spring where he can practice early spring irrigation, and thus not only insure a stronger and more vigorous crop during the critical budding season, but insure also an additional protection against possible danger from late frosts.

In comparing this method with the smudge, it would have been preferable had Mr. Thomas mentioned the character of the fuel used in making the smudge. While there is no doubt about the value of irrigation as a protection from frost, and the same should be used wherever practicable, still the communication of Mr. Thomas leaves a ground for doubt as to the comparative merits of this plan and the smudge. The writer is unacquainted with information from which a satisfactory comparison of these processes can be made, still there is no doubt of the advisability of using irrigation where it is possible, and if this is not found sufficient protection some of the wet-smudge methods should also be employed.

The protection obtained from spraying and irrigating is probably due to very similar principles. It is partly due to the evaporation of the water, which tends to increase the amount of moisture in the air, so that condensation will take place at a higher temperature.

However, the greatest amount of protection is probably due to the third principle of protection, namely :

III. ADDING HEAT TO THE AIR.

This results from the high specific heat of water. Owing to this property, about six or seven times as much heat is required to raise the temperature of water 1° as is necessary to change the temperature of most other substances by a like amount. Consequently, in cooling, six or seven times as much heat must be withdrawn from a mass of water as from other substances to produce the same fall in temperature. Dry soil will, perhaps, on an average, absorb 30 per cent of its weight of water, which, if at the soil temperature, will contain twice as much heat as the soil itself. Therefore, as radiation cools the earth's surface at night, this saturated soil will have three times as much heat to radiate as would be available were the soil dry. Its rate of cooling is therefore much slower, and the danger of frost is thus greatly decreased.

This effect is probably still further augmented by the water increasing the conductivity of the soil, so that, as the surface cools by radiation, heat from the soil beneath is brought to the surface more rapidly, thus making available a still larger amount of heat.

Undoubtedly, experiments as to the relative conductivity of wet and dry soils have been made, but the writer has not the data at hand for examination, and therefore can not make an estimate of the benefit to arise from this principle; it is evidently considerable.

While irrigation is undoubtedly a valuable protection, there is one

caution that must be considered in its use. Plants are much more easily damaged when full of moisture and sap, and when growing rapidly, than when drier and in the semi-dormant state in which they remain during the winter. Therefore, the danger from frost will be lessened if the early spring growth be retarded. To irrigate the soil with *warm* water (which would afford the best protection) will tend to hasten the spring growth. On this account, the ground should be irrigated only when necessary for protection during the period when frost may occur.

The use of *cold* water in irrigating would render much less protection from frost, but would tend to delay the growth so that buds would not open until the frost season had passed.

DIRECTLY HEATING THE AIR BY MEANS OF FIRES.

Mr. Edward Copely's plan.—Mr. Edward Copely, of Riverside, Cal., in several articles published in the Riverside Press of April, 1896, describes at length experiments which he has made in heating the air directly by small fires of coal, placed in wire buckets hung a short distance above the ground. In his discussion, he takes into consideration the fact that on frosty nights the air for some distance above the ground is considerably warmer than the surface, consequently it would be possible to warm the lower air until its temperature and resulting density were equal to those of the air above the surface before there would be any tendency of the surface air to rise and escape. Therefore, he believes that it is possible, by means of small fires, to warm the lower stratum of air sufficiently to prevent frost and at the same time avoid loss of heat, which would result were there an upward draft of sufficient force to carry the heated air above the tree tops.

The difficulties experienced in all methods of directly heating the air arise from the unequal distribution of the heat through the lower portion of the air, on account of which the warmer masses of air rise above the region needing protection, and cold, denser air is continually flowing in from the sides to replace them. Of course, this upward draft will be less with small than with large fires.

During the winter of 1897-98 a number of unusually severe frosts occurred in the citrus region of California. Advantage was taken of these occasions by the Horticultural Club of Riverside to test many devices. Below is given an account of these experiments which were probably the most extensive and carefully conducted of any ever made in this country. These show very conclusively the value of these small fires in protection in such a dry climate as exists at Riverside. In fact this method proves the most satisfactory of all those tested, and a similar result will probably be found to be the case in places where the dew-point is 10° or more below the temperature of

the air at times of danger. From what the writer is able to learn he does not think the trials of the damp smudge were generally made in the most efficient manner; however, in very dry climates, the vapor of the wet smudge diffuses throughout the surrounding space without condensing, thus rendering that method of protecting inefficient.

REPORT OF EXPERIMENTS IN FROST PROTECTION MADE BY THE RIVERSIDE HORTICULTURAL CLUB DURING THE WINTER OF 1897-98.

Preliminary Report by E. W. HOLMES and B. E. WILKIN.

Desiring to obtain reliable data as a guide to action by orchardists in preventing injury from frost, the Riverside Horticultural Club, after considerable discussion over the various theories presented, appointed a committee, of which J. H. Reed was chairman, to institute a series of practical experiments with the appliances made use of in the valley for that purpose.

Securing the assistance of an excellent corps of helpers, and carefully organizing the work to be done, Mr. Reed arranged for a thorough test of the different methods and fixed upon Saturday night for the first tests. It proved one peculiarly fit for the investigation.

Eight different plats were laid out, with a proper committee at each to make frequent observations during the night. In addition, five gentlemen were assigned the work of going over the whole ground to be able to make comparisons and qualify themselves to correctly judge of the details to be later furnished by the subcommittees. Professor Zumbro was of this committee, and made tests of humidity and temperature in and outside of the tracts where the different heat making processes were being carried on.

As the subject is one that demands prompt reporting, that the points gained may be made immediately available, I will anticipate the formal report, to be made to the Club when the data gained has been put in shape, and give to the public a few of the important results. The conclusions expressed are such as I have personally reached, and these may be in some degree modified upon a study of the figures to be furnished by the different committeemen.

The tests were made between Magnolia and Indiana avenues, in a section where the best opportunity is afforded for getting conditions as nearly as possible uniform, and were scattered over an area a mile and a half across.

In this section the mercury was 30° before the work commenced, at 2:30 in the morning, and in all the orchards was tending downward when operations began. Indeed, the night was much colder than was anticipated, and the temperature was near the danger point in a large portion of the valley before morning.

It gives me great pleasure to announce, as the result of the work of Saturday night, that henceforth there need be no serious loss of fruit in the average situation, where there is organized preparation on lines now demonstrated to be valuable.

It is not proper to give in detail before the committee's report is made public all the particulars of the study made, but I desire to state a few points regarding which I feel reasonably sure.

I do not feel certain that the experiment with moist straw burning demonstrated its value except as an adjunct to other methods. In the orchard where this was used there were excellent cypress wind-breaks, which helped materially in holding up the temperature. In this orchard the mercury stood uniformly 1° higher than in adjacent orchards, but I do not think it can be certain that the

smudge may have all the credit of this. The committee propose to give more thorough tests of this system before finally giving an opinion.

The steam apparatus of Mr. Hall, used near, and under similar local conditions, gave identical results with the straw test; but this test was not satisfactory, since a single machine could not be expected to change conditions over so large an area.

The steam apparatus on the navel orchard of Mr. Grant, the most complete of the kind yet used, did not raise either the dew-point or the temperature in the least. It is possible that if forty had been used instead of ten the result might have been different. But I am not inclined to believe success can be attained by this process. The truth is that the dew-point was not raised perceptibly, as was expected, and the cold increased until it reached the dew-point. The moisture settled and turned into frost on the leaves of the trees, and the temperature was not different after four hours' test from that in the open plain near.

But in the seedling orchard near, where twenty coal baskets to the acre were burning, we found the temperature 4° higher than in the navel orchard referred to. The tests showed that in seedling orchards near, where no work was being done, but where wind-breaks and the large trees themselves gave some protection, the mercury showed 2° more heat than in the navel grove, where the steam was generated, and this proved that the coal fires had raised the temperature at least 2° , enough in this case to absolutely insure safety.

On the Copley place the coal baskets were used, and only ten to the acre showed a difference of 1° early in the test, but later a difference of 2.5° over similar orchards adjacent.

I was skeptical about the value of this method when so few fires were lighted, but I now admit that the result shows this system deserving of general use, though I think not less than fifty baskets should be used if one would expect to increase the temperature sufficiently in a really cold spell to warrant effect.

But the test that gave the best result, and one so marked as to prove beyond all doubt the practicability of frost preservation, was that upon the Everest Ranch.

On the north line was a dense cypress row. On the east, from which direction came a drift of air of about 27° temperature, was placed a row of oil buckets, the fires being so near each other that the heat was very perceptible to one standing between them. Below them for several acres were burning oil pots, scattered some three rows apart each way. The trees were fair-sized navels, but not large enough to materially modify the temperature. A test near the row of fires on the windward side gave 32° . Several other tests in various parts of the area showed practically the same temperature, while 10 or 20 rods away 27° was indicated. Here was clearly a gain of 5° by artificial heating of "all out doors."

The oil fires were very hot and created a cloud of smoke very objectionable. But I could not but feel that coal baskets two or three times as numerous and arranged in the same way, with a massing of the fires to windward, would attain equal results, with less objection in the way of smut and less expense and trouble.

The section where a half acre was protected by a screen overhead showed 30° , and everything under it safe.

The water spray system gave no indication of increased temperature, the temperature being exactly the same as it uniformly was where no fires or smudges were made.

On Magnolia avenue, in the line of the drifting smoke, the mercury was 1° higher than where the fires and smoke had no influence.

I concluded from the above that our hope is in dry heat, rather than creating

artificial humidity, and for the first time feel confident that except in exceptionally cold sections the preservation of an orange crop, even in very cold winters, is possible.

Respectfully yours,

E. W. HOLMES.

The following is a report from the effects of burning straw on the ranch of Dr. Baird, near the corner of Indiana avenue and Monroe street, between Monroe and Jackson. The firing was done by W. P. Legg and B. E. Wilhite of Arlington place. On Friday night, December 3, they burned on 10 acres 2 tons of straw, raising the temperature from 26° to 28°, on an average. On Saturday night, December 4, they burned three-quarters of a ton on the same 10 acres, raising the temperature from 28° to 29°, on an average.

On Sunday night, December 5, they burned 2 tons more, and the temperature ran from 24° to 26°, on an average. By placing the thermometer within a distance of 6 feet of the flame of straw the thermometer ran from 24° to 29°.

Now, if a little medicine will help a sick man, increase the dose and he will get well. If a little fire will warm you, more fire will make you sweat. There are, on an average, 10 flakes of straw to a bale, and 20 bales to the ton, or 200 flakes. Place one flake to a tree over your orchard, or a quarter of a ton to the acre, and at about 4 a. m. light them by pouring a little oil on the straw. It will take about 2 gallons to light 10 acres. When lighted, go over the orchard with a pitchfork and touch and relight what did not burn, and those that are burning stir up with the fork. By the time you get over the second time the sun is up and everything made safe. You are out \$12 for straw, \$4.50 for help to distribute the day before, which should always be done beforehand; \$2.50 for lighting, and 32 cents for oil—or a total of \$17.32 for each real cold night. If there are six such in one winter, you are out just \$103.92, or about \$10 per acre, and there are seldom over three nights of danger, and a crop worth \$2,000 is saved for \$103.92. This is a great thing, and the beauty of it all is that you scatter straw and ashes over your place, and of a cold winter your place is sufficiently fertilized and you are out comparatively nothing for frost protection. All the Riverside people should arrange for this and warm up the valley on the coldest nights. Coal is good, but you are out the expense of buying the baskets and placing them over the orchard and taking them in, and in the end get no fertilizer. I wish the people would look into this matter and do something that would make everyone happy.

B. E. WILHITE.

Final report of the committee of the Horticultural Club.

At the last meeting of the Riverside Horticultural Club the committee appointed to investigate the question of orchard protection made its report, which was adopted, as follows:

Your committee, appointed to investigate the subject of frost protection, has performed the duty assigned it, and herewith submits its report.

With the assistance of some fifteen or twenty citizens interested in the study of the points involved, a most complete test has been made of the many different methods employed to prevent frost damage. With such a force of competent and impartial observers, it was possible to secure data of much value in forming an estimate of the efficiency of the various plans made use of. Careful comparison was made between those orchards where no work was done, and where no direct effect of the fire was probable, and those where the different methods were being tried. As indicated by our partial report at the last meeting of the Club, these tests were in some particulars eminently satisfactory, as showing the way to definite conclusions.

The exceptionally long period of cold following gave additional opportunity to verify the first conclusions reached, and subsequent investigations made by ourselves, as well as by other citizens who have awakened to the possibility of protecting their property, strengthened and confirmed the opinion formed as the result of the tests already partially reported upon.

Some theories are proven to have little practical value, and members of your committee have modified their views somewhat in consequence. No preconceived notions have been allowed to stand in the way of a thoroughly practical study of the facts as they exist, to the end that the growers may not, for the lack of definite knowledge as to the direction their efforts should take, neglect reasonable precautions hereafter to insure the safety of their crops. These, therefore, are our conclusions:

First. There is no doubt whatever that the temperature of our orchards may be materially raised by the use of dry heat.

Second. The radiation of the earth's heat can be very considerably lessened by moist smudges, when these are started early enough and are properly managed.

Third. The possibility of raising the dew-point on one of the dry, cold nights peculiar to our climate, sufficiently to prevent damage, by means of steam-producing apparatus, seems impracticable.

Fourth. Fruit and trees can undoubtedly be saved, even in the coldest sections, by covering them with cloth or matting; but the expense involved makes this method impossible on the part of the ordinary grower.

Fifth. It is found that the temperature in an old seedling grove, or where tall wind-breaks afford to smaller fruit trees a like protection, the temperature is almost invariably 1° or 2° higher than in exposed orchards in the immediate neighborhood. This fact seems to thoroughly upset the theory, strongly held by many intelligent growers, that the tall, well-located wind-break is a disadvantage, the contrary seeming to be the truth.

Sixth. It is found that the temperature 20 feet above the ground is from 1° to 2° higher than at the surface, and that, as a rule, when the cold is severe enough to injure the ripest fruit, 50 feet from the ground there is almost invariably a temperature above the freezing point of water.

Professor Zumbro, who has given especial attention to this matter, finds that at the height of 50 feet the temperature is from 5° to 10° higher than at the surface when the air is not in motion. When there is any considerable breeze, it varies but little.

Seventh. Our conclusion is that, all things considered, the coal baskets, sufficiently numerous, will prove the most satisfactory and effective means of warming the orchards yet made use of. It is true, the oil pots make a far hotter fire, and are neither expensive nor difficult to manage; but the deposit of lamp black upon tree and fruit, resulting from their use, condemns this system for general use.

As to the value of smudging the members of your committee are not so well agreed. Because of less sharply defined results, we find it more difficult to come to definite, at least uniform, conclusions. But, under certain conditions, we are convinced that, properly used, it may be made a valuable means of protection. We think this especially true in localities where the temperature never falls but little below the danger point, and where there are considerable solid areas of young orchards exposed. Here it will work well if the protection is made general. But where the danger is considerable we think it wise to be prepared to use dry heat even where in connection with the smudge. The benefit from smudging is probably as much from its protecting fruit and trees from the sudden rays of the morning sun after a freezing night as from modifying temperature during the time of danger.

Experience demonstrates that flooding or running water in connection with dry heat or smudging is a valuable adjunct. One of the committee who has been testing this matter carefully for three years, is disposed to think that the direct benefit from running water is overestimated by the majority of growers. Its value in putting orchards in condition to withstand quite severe weather safely is unquestioned, but the committee are inclined to think that entire dependence upon this method will occasionally result in serious loss to those who trust to this means alone, especially when used in young orchards.

As to the number of baskets needed when coal is used, we find the most decided and satisfactory results have been gained where from twenty to fifty coal fires have been used to each acre. If intelligently and energetically used, this plan will never fail, except when the mercury drops below 24° for a long while, and even then it is believed the larger portion of the crop may be saved if anything like a general use of such fires be secured. The smaller number of fires named has, in numerous cases, and even when a man was working alone, secured a rise of from 3° to 5° , and saved a crop. Can it be doubted that fifty fires per acre, used in every orchard, would save both trees and crop on the coldest night ever known in California's history?

To equip an orchard with fifty baskets to the acre means an outlay of only a little over \$5. The fuel to run them one night costs from \$2.50 to \$3. If a crop of navels upon it is worth \$400 it will pay well to spend in fuel and labor \$4 per night, or one per cent on the value of the crop to insure its safety. In the orange region of southern California it is not usual to have more than two or three nights in a season when the fruit is in danger. But even if, as in the present season, the period of cold is more extended, will it not pay to expend at least as much as one pays for his irrigating water to secure the safe maturing of a crop it has cost him a year's labor and heavy expense to produce?

The conclusion is obvious that we have only to provide for the insurance of this sort of property exactly as we would in the case of that liable to destruction by fire, to be enabled to follow the business of orange and lemon growing with the certainty of having perfect fruit to market at the season's end.

While the practicability of protecting our orchards from frost seems established, the problem of the most economical and scientific means of accomplishing this is probably yet to be solved. However well the wire baskets may serve us now, there doubtless will be improved methods for burning coal, and even other material may be found that will serve the purpose better, and while wet straw seems at present to be the most available for smudges, doubtless, when the need is made known, chemists will find some vapor-producing material more compact, efficient and economical. Hence we recommend that the Club appoint a permanent committee to continue these investigations.

Respectfully submitted,

J. H. REED,
E. W. HOLMES,
E. L. KOETHEN,
E. A. ZUMBRO,
J. H. MARTIN.

The following letter of Mr. E. W. Holmes, president of the Brocton Square (Riverside) Association, for preventing injury from frost, gives the results of some experiments made in November, 1896, at the same place, in which the damp smudge appeared to give the best results:

ORCHARD PROTECTION.

Impressions of a practical orchardist regarding the experiments made.

EDITOR PRESS: By request of several who were present at the experiments made upon the Meacham Ranch, I give you my impressions regarding the various tests of frost protection there made. I have had little opportunity to consult with others, and the opinions I may express are personal and such as are hastily formed from observation of the tests. The community is under obligation to the Meacham Brothers for affording an opportunity to study the different methods advocated for securing frost protection. They had arranged several rows of pots containing crude oil, over which were stretched wire netting, upon which was spread wet straw. Barrels of water were located conveniently, so as to keep the straw moistened. Upon another section of the orchard were rows of suspended wire baskets, each containing about 10 pounds of coal. There were apparently about twenty of these to the acre. In another row was an experiment with wet baled straw, in which fire was started by pouring kerosene upon it. Near this was a quantity of wet peat, ignited in the same way and used in connection with moistened straw.

The experiments made with the coal baskets have been so often described that no detailed reference is required. They were set on fire at about 5 o'clock, and were still burning at 8:30, without having required any special attention. The heat generated did not appreciably affect the temperature of the orchard, and the smoke was much less dense than that given off by the other fires. This is the method most easily handled, and by the saving of labor and definiteness of expense involved is most attractive to the orchardist who depends entirely upon his own exertions at the critical time. I am inclined to believe that a much larger number of baskets is required if these baskets are to be used alone. Whether the larger use will not involve expense equal to the other plans is a question. I think that it would be better not to increase the number, but to use them in conjunction with some steam-producing appliance.

The oil pots blazed up hotly when set going, and the flame, filtered through the dense moist straw or manure, set afloat a white cloud that drifted low through the orchard, and remained suspended among the trees until it had floated a long distance to leeward. Of the value of this method there can be no question; but the labor involved in keeping the straw properly wet, the pots from boiling over, or the fire from going out, is considerable. It is, also, in spite of the fact that the straw served as a filter and held an immense proportion of the lampblack, a dirty method for those engaged in the work.

The wet baled straw, while furnishing a less amount of heat and steam, required comparatively little attention. It is the cheapest of the three referred to, as the straw or stable bedding is not expensive, and if unused is worth all it costs as a fertilizer. Nearly every ranch affords the means for such a fog-producing method, and those who are deterred from assisting in a general effort, on account of the expense, are likely to give this a trial.

The experiment with the peat seemed to me hardly as satisfactory; but some better way of using it may be devised. It struck me that when saturated with water it is hardly more inflammable than a wet sponge, and that it could not be used the same as the wet straw, which smolders away even when thoroughly dampened. The cloud of moisture and smoke drifted for a mile or more down the valley, and showed no disposition to rise, as is the case when hot fires have been built.

The temperature in the orchard was not raised as much as I anticipated by the numerous fires, and this was at first discouraging. There was one point brought out, however, that deserves to be considered before one concludes that the

experiments failed of the success desired. And I am inclined to think those who are best posted in these matters will say that this point is the one upon which we may base our hope of success.

I found the trees in the center of the grove fairly dripping with moisture. Calling attention to this as an evidence of the good accomplished, a friend urged me to examine the trees outside of the area of the fires. I found that 10 rods distant, and not in the line of the drifted smoke, there was also moisture upon the foliage. But immediately upon reaching my own grove, a mile distant, ten minutes later, and before sunrise, I found the foliage everywhere absolutely dry. The mercury had not been raised in the grove appreciably by the many fires, but the question immediately occurred to me that I had discovered a result which might promise us security. If the thermometer had indicated 32° instead of 40°, and the general conditions were such as to send it to 26° without the use of the steam smudge, would not the presence of all this immense quantity of moisture in the atmosphere, produced by these local causes, so nullify the effects of the general condition as to preserve the tenderest fruit and foliage from freezing? I think it would. If not, then I am inclined to believe that no method at our command is of value.

I conclude, therefore, that no method is worth considering that does not include the generation of steam, and that whether we use coal, crude oil, or any other fuel, we need to join with it some plan that shall fill the air with moisture. This much seems to me to be demonstrated, and I confess that if this idea is not sound I am not sanguine of the success of any plan yet suggested.

The coal baskets are the easiest worked, and why can not a portion of them be so arranged by the placing of wet straw or manure above them upon a bit of corrugated iron as to use the coal in producing steam as well as heat.

In spite of the fact that the temperature was not raised as much as was anticipated by the numerous fires at this morning's experiment, the impression seemed general among those present that much had been gained by the morning's work, and that all that was needed to secure success was the united action of the growers.

The different conclusions arrived at in these two series of experiments made at the same place, and mainly by the same persons are probably in great measure due to the amount of moisture present. It is believed that when the air contains sufficient moisture, so that the amount added, by vapor-producing methods, will cause condensation of moisture and deposit of dew at a temperature above the point of injury, then that method will be found efficient. This will probably be the case when the difference between the readings of a common thermometer with a dry bulb and one with the bulb covered with a thin layer of moist muslin is but 3° or 4°. The coal baskets will prove the more efficient the greater the difference between the temperature of the air 5 feet above the ground and at the tree tops. Unless the temperature at the height of the tree tops is 2° or 3° warmer than at the height of the lower limbs little benefit is to be expected. The smaller the fires and the greater number to the acre, the greater the protection for the same amount of fuel.

IV. DRAINING THE COLD AIR FROM THE REGION NEEDING PROTECTION.

Mr. J. E. Cutter, in the *Riverside Press* of January 18, 1896, pub-

lished several articles on the subject of "Frost Protection." In these articles he called attention to the fact that on frosty nights the radiation cools the air near the surface, which increases its density and causes it to flow down the hillside and through the valley in a manner similar to the flow of water on sloping surfaces. This cold air collects in the lowest portion of the valley and slowly submerges the trees, frequently causing killing frost in such a location, while no injury results to the trees on the surrounding hills. He suggests warming the air by large bonfires. This may be feasible. Such fires should be placed at the lowest portion of the valley. They will draw into them the cold air near the surface, which will then be heated and pass upward, thus keeping up a continuous draft of the cold air toward the fire. It is very doubtful if better protection might not be obtained by the expenditure of the same fuel in small smudge fires.

Air drainage.—It may be possible, in many instances, to permanently remove or greatly diminish the danger arising from the flow of cold air down the hillside into the valley by constructing wind-breaks, so placed as to drain off this cold air from the locality. The breaks could be in the form of a high, closed fence or levee. Preferably there should be a levee 4 or 5 feet high, with the ditch on the side next the hill, into which, if possible, water should be turned. On the top of the levee a closed fence should be placed. The evaporation of the water from the stream would tend to raise the dew-point of the air. The levee should be so placed along the slope near its base as to intercept the cold air and lead it beyond or around the orchard. It should have a continuous slope downward, the steeper the better, so that the cold air will not overflow it.

V. MIXING THE AIR SO AS TO PREVENT THE COLD AIR FROM SINKING TO THE SURFACE.

While many of the preceding methods depend partly on this principle for their success, the writer is not familiar with any process which depends solely upon it.

WHEN AND HOW TO PROTECT.

The experience of the past two seasons has shown that forecasts of sudden and decided changes in temperature over a large territory are among the most accurate made by the Weather Bureau; consequently, it is reasonable to expect that, if suitable arrangements are made, warnings may be received of those otherwise unexpected cool waves which will result in frost. There are instances, however, when the general forecasts of the Weather Bureau can not be expected to be sufficiently specific to provide for the different conditions that may prevail in various sections. The temperature frequently remains for several days near the critical point, and a change of a very few degrees

or a local clearing or clouding of the sky will cause or prevent injury. Again, the conditions in certain localities are such as to make them more susceptible to frost than the surrounding region. Prof. Willis L. Moore, Chief of the Weather Bureau, states that, while forecast official in Wisconsin, he observed that a frost occurring immediately after a rain was not as injurious as when the ground and plants were dry. It is therefore necessary that the orchardist and gardener be able to judge, at times, for themselves when danger from frost is imminent. For this purpose they should be provided with a wet and dry-bulb hygrometer, by which can be determined the dew-point of the air or the temperature at which condensation takes place. Condensation checks the fall in temperature on frosty nights. Frequent observations with this instrument should be made.

If, in the afternoon, the dew-point is near the critical temperature, arrangements should be made for protecting, if necessary. If, at a later hour, the dew-point is constant or lower, the sky clear or clearing, and the air calm, it is reasonable to expect that the temperature will fall to the dew-point during the night. The efforts to protect should be based on this dew-point. If it merely approximates the danger point (and no warning of more severe temperatures has been received) but little protection will be necessary, and action may be delayed until the temperature is but a few degrees above the danger point. However, if the dew-point be several degrees below that liable to cause injury, or if it be falling, or if a change for the colder be anticipated, efforts to protect should be undertaken earlier.

No specific rules of universal application can be laid down for the guidance of the orchardist in protecting. The same intelligent, careful, and systematic attention must be given to this as to other subjects in order to secure success. However, the following suggestions may be of value:

Irrigation should be resorted to wherever possible. The water should be turned on during the day preceding the night when frost is anticipated, and continued until the ground is thoroughly saturated.

In all sections it is recommended that either coal baskets or some method for causing a wet smudge be used, or a combination of both. The coal baskets will be found the more useful the drier the air and the greater the excess in temperature 30 or 40 feet from the ground, and near the surface, as previously explained. For the purpose of determining this difference a pole 40 or 50 feet long, with halyards, like a flagstaff, should be erected in the orchard. Two thermometers should be attached to the halyards, so that as one thermometer is at the top of the pole the other is 5 feet from the surface. Leave one thermometer at the top of the pole for five minutes; read the one near the ground, and then quickly lower and read the one which has been at the top of the pole.

When coal baskets are used there should be from twenty-five to fifty of them used to the acre, depending on the intensity of cold, as described in the reports of the Horticultural Club of Riverside. When the wet smudge is used probably better results would be obtained from a combination of the portable and stationary smudges. About one wagon or sled, arranged for carrying an evaporating fire, should be provided for each 50 acres. In addition, stationary smudges should be used. The material for these should be prepared at the beginning of the frost season, and kept in readiness for immediate use. Sacks filled with wet manure or bales of wet straw should be distributed throughout the orchard. The sacks should be placed about 75 feet apart each way, at the intersection of the rows. A smaller number of bales of straw is necessary. Hollows should be dug a few inches deep about each sack, and, if the sack becomes dry before being used, a pailful of water should be poured upon it, which will remain in the hollow near the sack until absorbed. Whenever it is necessary to protect, an effort should be made to determine the direction in which the air drifts across the orchard. And the sacks should be fired in rows running *across* this draft, beginning at the windward side of the orchard. Every sack should be ignited in the row, but only every third or fourth row need be burned the first night; the remainder being available for succeeding nights. In setting fire to the sacks, one man goes ahead with a pail of coal-oil and pours about a pint on each sack; and another, following with a torch, ignites them. In the meantime, portable smudges should be put in operation. They should be driven forward and back between the rows and across the drafts of the orchard. It is very desirable, if not essential, that the superintendent take a position on the most elevated point at his command, as the top of a house, barn, water tank, or windmill, from which he can observe the drift of the smudge and direct the movement of the teams so as to secure the best results.

It would seem that these precautions should be sufficient to prevent injury, unless it be in the case of narrow valleys, where the cold air from the unprotected hillsides displaces that which has been kept warm, and, should wind-breaks be found successful in removing this danger, it is believed there are few, if any, localities where injury could not be avoided.

It is evident that in attempting to protect one ranch the owner will, in a measure, protect his neighbor; therefore, if some arrangements for cooperation among the individuals in the same locality were made, the greatest protection could be provided at the minimum expense. By such a cooperation of all the residents of the valley, a system of wind-breaks or air-drainage dikes (if found valuable) could be laid out and built in such a manner as to result in the greatest general good at the least cost. Arrangements could be made which

would insure the distribution of a frost warning from the Weather Bureau throughout the entire district. Some person, provided with a telephone, could receive the warnings from the Bureau, and, in turn, telephone them to all others having such instruments. All so receiving them could display the frost signal, and thus the warning would be quite generally distributed.

Some person in each locality or ranch should study the peculiarities of his section. He should thoroughly understand the conditions under which frost forms, should provide himself with a psychrometer, and take frequent observations on afternoons and evenings when frost is imminent, and thus be enabled to give the most accurate information possible to his locality. He would probably thus prevent the inconvenience and expense connected with protecting when the local conditions or a change in the weather were such as would prevent a frost, and also he would be likely to discover times when frost was imminent when no warning had been received. This man, indeed, should be a sort of local expert on this subject.

The following notes on frost protection for citrus fruits at Riverside (being the individual report of Mr. E. L. Koethen, a member of the Frost Protection Committee of the Riverside Horticultural Club, and secretary of the club) are so excellent and many are of such general application that their perusal is recommended to all:

1. In sections where there is a prevailing draft from a certain direction concentrate the fires somewhat on the sides of the orchard from which this draft comes.

2. Some fires are needed all through the orchard.

3. If the thermometer should reach 26° by midnight, start firing at once. If smudging is to be depended upon, you should commence much earlier. To be safe, commence lighting baskets, if the thermometer should reach 26°, as late as 4:30 a. m.

4. Ripe fruit will stand more frost than green fruit. The above figures are for ripe fruit.

5. The thermometer may go many degrees below the dew-point in our climate on nights when the sun sets behind heavy clouds.

6. A mild day may be followed by a night of danger to citrus fruits.

7. The upper strata of air are much warmer than the lower. Eight degrees was found to be the variation between a height of 5 and 50 feet, upon different tests.

8. Thermometers should be tested each year, and the variation noted and accounted for at each reading.

9. A good way to secure uniform observations and the extreme temperature to which fruit is exposed is to fasten the thermometer to a slender stick 5 feet long and place in the space between four trees, away from buildings or other shelter.

10. Every grove has some spot that is colder than any other. Find it, and be governed in your firing by the temperature there, keeping your eye on other locations, for the coldest place may shift around.

11. A thermometer that registers too high may be very comforting, but is not a safe guide unless allowance is made for correction.

12. A thermometer that registers too low may cost unnecessary labor, expense, and anxiety.

13. We need a united system of general alarm for localities throughout the valley.

14. Wind-breaks, parallel with the flow of the cold stream of air, are an advantage in preventing radiation.

15. Close wind-breaks, at right angles to the flow of cold air, will form dams and cause low temperatures on the upper side. A block of large trees below a block of smaller trees will have the same effect.

16. Coal baskets or brush fires concentrated at these points will drain off the cold air.

17. Flowing water is a help, but is not sufficient in itself.

18. Clean culture and a wet surface is the best condition of the soil in times of danger.

19. Trees that had suffered from lack of water at any time during the development of the crop and those with a dry surface of the soil suffered greatest injury.

20. Firing of any kind is beneficial if there is enough of it.

21. The cost need not be prohibitive for good results.

22. Accumulative firing is better than single-handed.

23. A single grower can succeed in saving his fruit with coal baskets if he has enough of them.

24. Be prepared to make more fires than you will likely need. The unexpected sometimes happens.

25. No grower should depend on his neighbors for heat or smudge. Every gap is an injury to the whole. Besides, your neighbors may not locate their fires so as to do you much good.

26. Coal baskets can be made for about 7 cents each. The filling will cost about 7 cents, where bituminous coal costs \$10 per ton, and you should have from twenty-five to fifty per acre, according to location and size of grove.

27. A little burning straw is a snare and deceit.

28. Straw smudge should be made from wet straw, should be dense, and should cover large areas to yield best results. Dry straw is of little value, except to help burn that which is very wet.

29. The efficacy of smudging being dependent upon preventing radiation in very dry climates, early lighting in such cases is imperative.

30. A little dry brush is a great help in burning very wet straw.

31. Green cypress boughs create a fine smudge.

32. Most groves have a cold corner. Have some brush piles ready to light at the critical hour—about dawn.

33. Coal baskets should be full at the start. Coal will not ignite readily in replenishing if a good bed of coals is not secured at first. A reserve supply of coal may be very useful if the cold is long continued.

34. Coal baskets need less attention than the smudge.

35. Have plenty of help. The better your fires are tended, the better the results.

36. But few employees can be depended upon to look after the details and carry on the work. *Your personal attention is needed.*

37. Every detail should be prepared beforehand. There is no time to hunt up torches and tools after the danger point is reached.

38. Oil fires will do good work, but the smut is objectionable.

39. Evaporating pans give no visible results.

40. An awning or cover was found to be of great service.

It may be believed that the trouble and expense necessary to carry

out these plans are greater than the benefits accruing from the protection, but this seems hardly true, as a general rule. The supplies needed in the various methods are inexpensive, straw, manure, old rubbish, prunings, etc., being excellent materials for fuel. A few old sacks and cheap sleds are the principal apparatus. The most essential supply is water. Coal baskets cost but about 10 cents a piece, and the necessary fuel for a night costs but from 1 to 5 cents, according to price of coal. Successful protection was accomplished during several nights last year, in many sections, at an expense of less than 1 per cent of the value of the crop. Really, the trouble, inconvenience, and labor, are practically the only drawbacks, while the gain may amount at times to many thousand dollars.

APPENDIX No. 1.

THE USE OF THE SLING PSYCHROMETER.

This instrument is a form of hygrometer most suitable for the use of the orchardist. It consists of two thermometers fastened to the same back and arranged for whirling. One of the thermometers has its bulb covered with thin muslin, moistened with water. The evaporation of the water about the wet bulb lowers the temperature and causes this thermometer to read lower than the one with a dry bulb. From the difference between these readings and the temperature of the air itself the dew-point can be quite accurately determined from the accompanying table.

Exposure.—While the psychrometer will give quite accurate indications, even in the bright sunshine, yet observations so made are not without some error, and where greater accuracy is desired the psychrometer should be whirled in the shade of a building or tree, or, as may sometimes be necessary, under an umbrella. In all cases there should be perfectly free circulation of the air, and the observer should face the wind, whirling the psychrometer in front of his body. It is a good plan, while whirling, to step back and forth a few steps, to further prevent the presence of the observer's body from giving rise to erroneous observations.

The wet bulb.—It is important that the muslin covering for wet bulb be kept in good condition. The evaporation of the water from the muslin leaves always in its meshes a small quantity of solid material, which, sooner or later, somewhat stiffens the muslin, so that it does not readily take up water. This will be the case if the muslin does not readily become wet after being dipped in water. On this account it is desirable to use as pure water as possible, and also to renew the muslin from time to time. New muslin should always be washed to remove sizing, etc., before used. A small rectangular piece, wide enough to go about one and one-third times around the bulb and long enough to cover the bulb and that part of the stem below the metal back, is cut out, *thoroughly wetted* in clean water, and neatly fitted around the thermometer. It is tied first around the bulb at the top, using a moderately strong thread. A loop of thread to form a knot is next placed around the bottom of the bulb, just where it begins to round off. As this knot is drawn tighter and tighter the thread slips off the rounded end of the bulb and neatly stretches the muslin covering with it, at the same time securing the latter at the bottom.

To make an observation.—The so-called wet bulb is thoroughly saturated with

water by dipping it into a small cup or wide-mouthed bottle. The thermometers are then whirled rapidly for fifteen or twenty seconds; stopped and quickly read. A mental note of the readings is made, when they are again whirled and read. This will be continued until the wet-bulb thermometer ceases to fall, when the readings of the two thermometers should be read and recorded. If the wet thermometer should read 32° , the whirlings and frequent readings should be continued for a considerable time, to be certain that a further fall will not take place. The freezing of the water at 32° causes the fall to be checked for a short time.

Subtract the reading of the wet thermometer from that of the dry. Find this difference in the line at the top of the table. The dew-point will be found at the intersection of the column beneath with the line which has the proper dry thermometer reading at the left.

First example.

Dry-bulb thermometer	55°
Wet-bulb thermometer	44
Difference	11
Dew-point from table	30

Second example.

Dry-bulb thermometer	43°
Wet-bulb thermometer	38
Difference	5
Dew-point from table, between 28° and 33° , about	30

Dew-point table—Fahrenheit temperatures.

t (Dry ther.)	Difference between the dry and wet thermometers ($t-t'$).																				t' (Dry ther.)
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°	
20	17	13	8	2	-6	-19															20
21	18	14	9	4	-4	-15	-47														21
22	19	15	11	6	1	-11	-31														22
23	20	16	12	7	1	-8	-24														23
24	21	18	14	9	3	-5	-18														24
25	22	19	15	11	5	-2	-13	-42													25
26	23	20	16	12	7	0	-9	-28													26
27	24	21	18	14	9	3	-6	-20													27
28	25	22	19	15	11	5	-3	-15	-54												28
29	26	24	20	17	12	7	0	-10	-32												29
30	27	25	22	18	14	9	2	-6	-22												30
31	29	26	23	19	15	11	5	-3	-15												31
32	30	27	24	21	17	13	7	0	-10	-33											32
33	31	28	25	22	18	14	9	3	-6	-22											33
34	32	29	26	24	20	16	11	6	-2	-15											34
35	32	30	28	25	22	18	13	8	+1	-9	-32										35
36	34	31	29	26	23	19	15	10	4	-5	-20										36
37	35	32	30	27	24	21	17	12	6	-2	-14	-52									37
38	36	33	31	28	26	22	19	14	9	+2	-8	-29									38
39	37	34	32	29	27	24	20	16	11	5	-4	-18									39
40	38	35	33	30	28	25	22	18	13	8	0	-12	-44								40
41	39	36	34	32	29	26	23	20	15	10	+4	-6	-25								41
42	40	38	35	33	30	27	24	21	18	12	7	-2	-15								42
43	41	39	36	34	31	29	26	23	19	14	9	+2	-8	-33							43
44	42	40	37	35	32	30	27	24	20	16	12	6	-4	-19							44
45	43	41	39	36	33	31	28	25	22	18	13	8	0	-11	-48						45
46	44	42	40	37	35	32	30	27	24	20	16	11	+4	-5	-24						46
47	45	43	41	39	36	33	31	28	25	22	18	13	7	-1	-14						47
48	46	44	42	40	37	35	32	29	26	23	20	15	10	+2	-8	-30					48
49	47	45	43	41	38	36	33	31	28	25	21	17	12	6	-3	-18					49
50	48	46	44	42	40	37	34	32	29	26	23	19	14	9	+1	-10	-42				50
51	49	47	45	43	41	38	36	33	31	28	24	21	17	11	5	-5	-22				51
52	50	48	46	44	42	40	37	34	32	29	26	23	19	14	8	0	-13				52
53	51	49	47	45	43	41	38	36	33	30	28	24	20	16	11	+4	-6	-28			53
54	52	50	49	46	44	42	40	37	34	32	29	26	22	18	13	7	-2	-16			54
55	53	52	50	48	46	44	41	39	36	33	30	28	24	20	16	10	+3	-8			55
56	54	53	51	49	47	44	42	40	37	34	32	29	26	22	18	13	6	-2	-19		56
57	55	54	52	50	48	46	44	41	39	36	33	30	28	24	20	15	10	+2	-10	-48	57
58	56	55	53	51	49	47	45	42	40	37	35	32	29	26	22	18	12	6	-3	-22	58
59	57	56	54	52	50	48	46	44	41	39	36	33	31	27	24	20	15	9	+1	-12	59
60	58	57	55	53	51	49	47	45	43	40	38	35	32	29	26	22	18	12	5	-5	60
61	59	58	56	54	52	50	48	46	44	42	39	36	33	31	28	24	20	15	9	0	61
62	60	59	57	55	53	52	50	48	45	43	41	38	35	32	29	26	22	18	12	+5	62
63	61	60	58	56	55	53	51	49	47	44	42	39	37	34	31	28	24	20	15	9	63
64	62	61	59	57	56	54	52	50	48	46	43	41	38	35	32	29	26	22	18	12	64
65	63	62	60	59	57	55	53	51	49	47	45	42	40	37	34	31	28	24	20	15	65
66	64	63	61	60	58	56	54	52	50	48	46	44	41	38	35	32	30	26	22	18	66
67	66	64	62	61	59	57	55	54	52	50	47	45	43	40	37	34	31	28	24	20	67
68	67	65	63	62	60	58	57	55	53	51	49	46	44	42	39	36	33	30	26	23	68
69	68	66	64	63	61	59	58	56	54	52	50	48	46	43	40	38	34	32	28	25	69
70	69	67	66	64	62	61	59	57	55	53	51	49	47	45	42	39	36	33	30	27	70
71	70	68	67	65	63	62	60	58	56	55	53	51	48	46	43	41	38	35	32	29	71
72	71	69	68	66	64	63	61	59	58	56	54	52	50	47	45	43	40	37	33	31	72
73	72	70	69	67	66	64	62	61	59	57	55	53	51	49	46	44	41	38	35	32	73
74	73	71	70	68	67	65	63	62	60	58	56	54	52	50	48	45	43	40	37	34	74
75	74	72	71	69	68	66	64	63	61	59	57	56	54	52	49	47	44	42	39	36	75
76	75	73	72	70	69	67	65	64	62	61	59	57	55	53	50	48	46	43	41	38	76
77	76	74	73	71	70	68	67	65	63	62	60	58	56	54	52	50	48	45	42	40	77
78	77	75	74	72	71	69	68	66	65	63	61	59	57	55	53	51	49	47	44	41	78
79	78	76	75	73	72	70	69	67	66	64	62	61	59	57	55	53	51	48	46	43	79
80	79	77	76	74	73	72	70	68	67	65	63	62	60	58	56	54	52	50	47	45	80
t	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°	t'

APPENDIX NO. 2.

INJURIOUS TEMPERATURES.

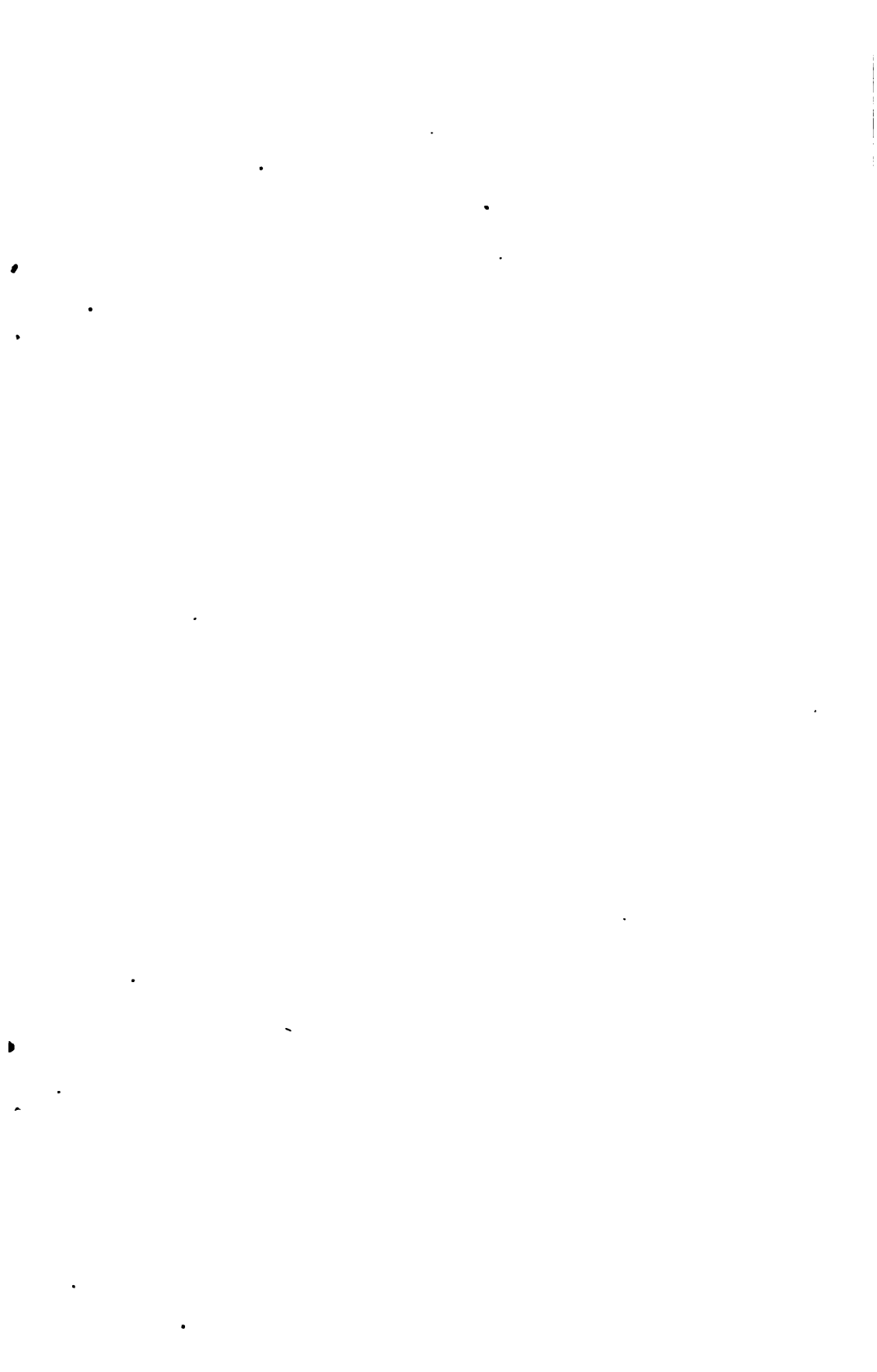
Table of temperatures at which the following plants are liable to receive injury from frost, compiled from information received from horticulturists, orchardists, and gardeners throughout the entire Pacific coast.

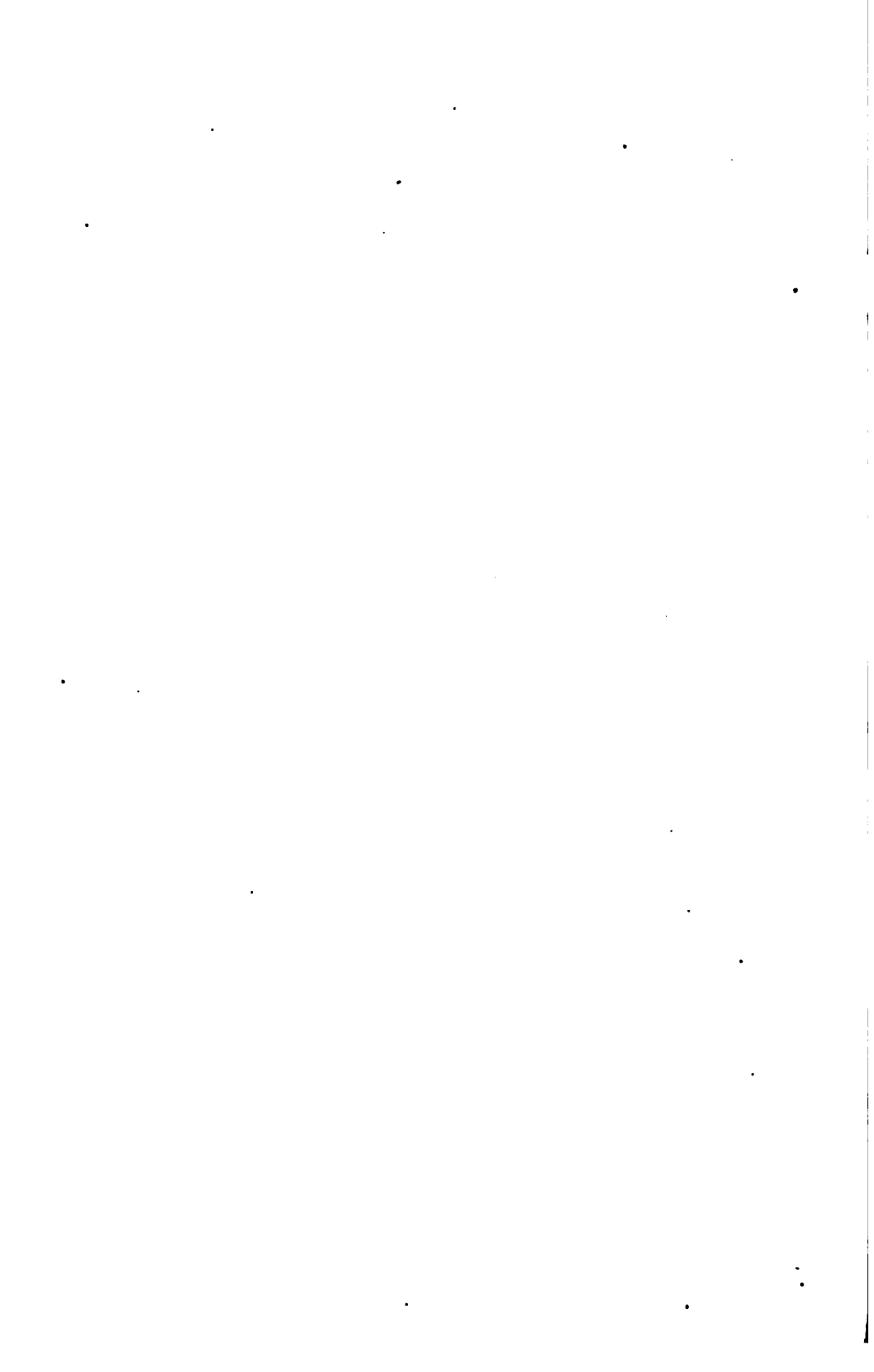
The temperatures given are, as nearly as possible, those of the air in contact with the plant itself.

Plants or fruits.	In bud.	In blossom.	In setting fruit.	At other times.	Plants or fruits.	In bud.	In blossom.	In setting fruit.	At other times.
Almonds	28	30	30	28	Onions	30	31	31	28
Apples	27	29	30	28	Oranges †	30	31	31	{ 28 29
Apricots	30	31	32	30	Parsnips				27
Asparagus	29	30	32	28	Peaches	30	30	30	29
Bananas	31	31	32	31	Pears	28	29	29	28
Barley		29			Peas	29	30	30	28
Beans		31			Plums	30	31	31	28
Beets				28	Potatoes:				
Cabbage				15-27	Irish	30	30	30	31
Cantaloupes	32	32		30-31	Sweet	31	31	31	31
Cauliflower				20-27	Prunes	30	31	31	29
Celery				28	Radishes				28
Cucumbers	31	31	31	32	Shrubs, roses, or trees.	28-30	28-32		20-28
Cymlings or squash	31	31	31	30	Spinach				31
Flowers*	31	31	31	30	Strawberries	28	28	28	30
Grapes	31	31	30	28	Tangerines	31	31	31	28
Grape fruit	30	31	31	28	Tomatoes	31	31	31	31
Lemons	30	31	31	28	Turnips				28
Lettuce				12-28	Watermelons				28-31
Mandarins	31	31	31	28	Wheat		31	31	.....
Oats	31				Walnuts, English	30	31	31	28
Okra				31					
Olives	30	31	31	{ 18 24					

* Depends on variety. † Injured at 2° higher if continued four to six hours. ‡ Ripe. § Green.







Bulletin No. 24.—W. B. No. 187.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

U. S. DEPT. OF AGRICULTURE
JUN 25 1899

PROCEEDINGS

OF THE

CONVENTION OF WEATHER BUREAU
OFFICIALS,

HELD AT

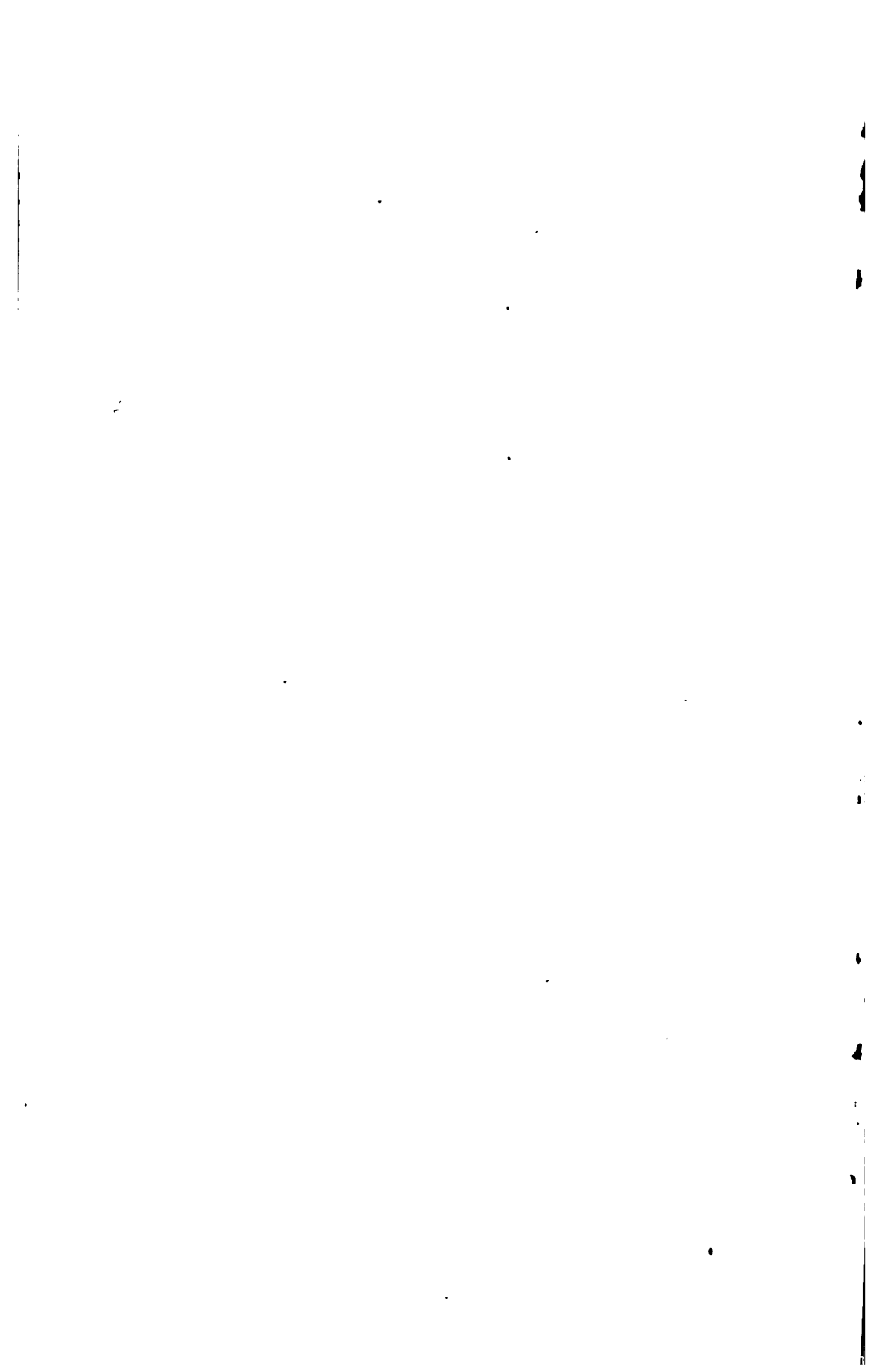
OMAHA, NEBR., OCTOBER 13-14, 1898.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

Edited by JAMES BERRY,
Chief of Climate and Crop Division, Secretary of the Convention.



WASHINGTON:
WEATHER BUREAU.
1899.



LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., January 9, 1899.

HON. JAMES WILSON,
Secretary of Agriculture, Washington, D. C.

SIR: I have the honor to transmit herewith report of the proceedings of the Convention of Weather Bureau officials held at Omaha, Nebr., October 13-14, 1898, and recommend its publication as a bulletin of the Weather Bureau, the edition to be 5,000 copies.

Occasional conventions of Weather Bureau officials are regarded as very important, as they afford opportunity for exchange of views, discussion of methods, and means for advancing Weather Bureau work.

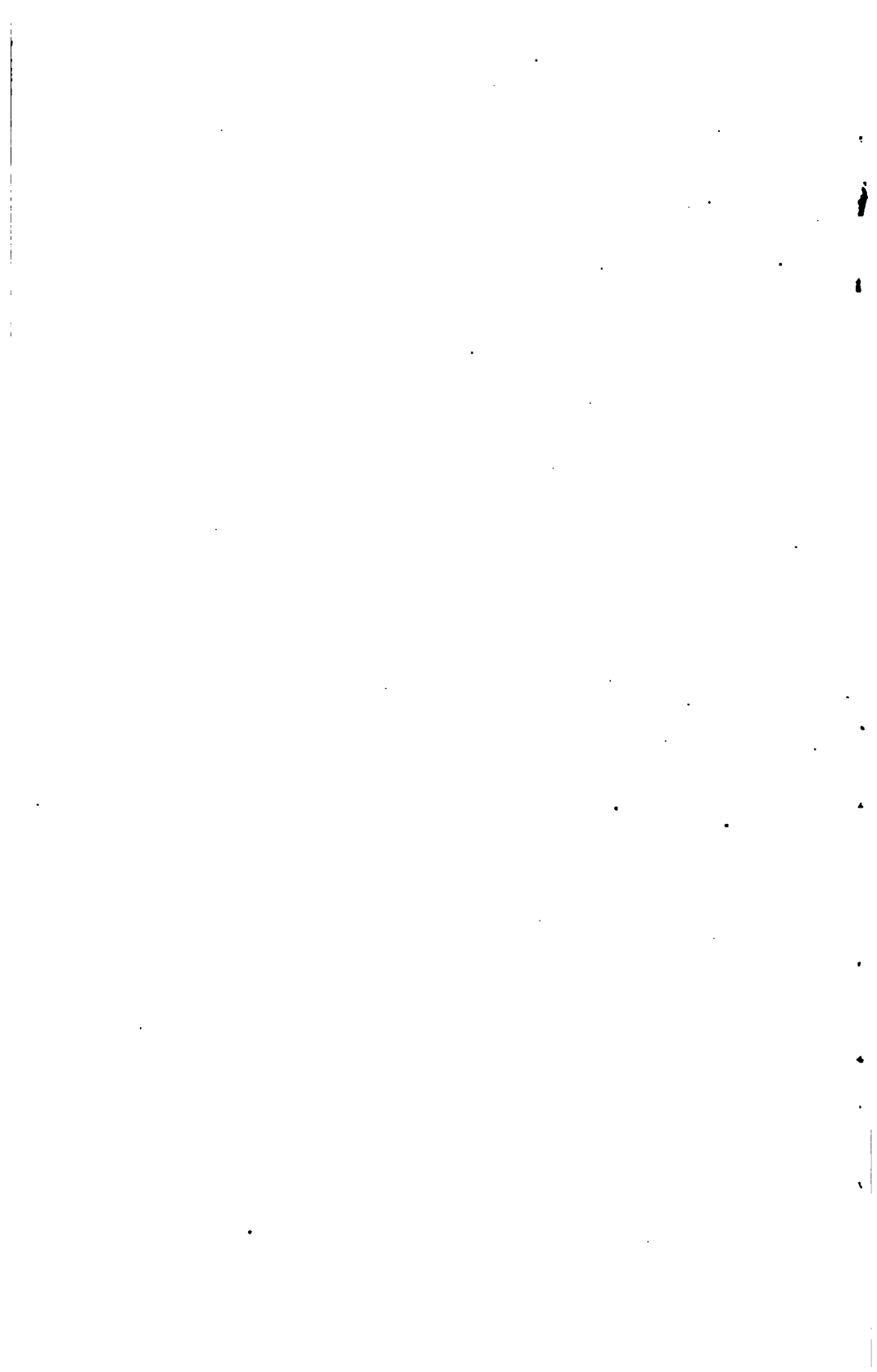
Conventions have been held in former years, but heretofore the subjects discussed have been restricted to the Climate and Crop feature of the service. The deliberations of the Convention of 1898, however, were of wider scope, covering practically the entire range of work of the Bureau, and the attendance was more than double that of any previous meeting.

The accompanying report contains many papers of exceptional merit that will prove of interest and value to the employees of the Bureau, as well as to its large corps of voluntary observers, forecast displaymen, and climate and crop reporters.

Very respectfully,

WILLIS L. MOORE,
Chief U. S. Weather Bureau.

Approved:
JAMES WILSON
Secretary.



CONVENTION OF WEATHER BUREAU OFFICIALS.

The beneficial results following the numerous conventions of State Weather Service Directors held in former years were so pronounced as to convince the Secretary of Agriculture that such gatherings should not only be held at stated intervals, but that those participating therein should not be restricted to officials engaged in any special line of work, as had been the case with the American Association of State Weather Services. He therefore decided that the scope of such conventions should be so extended as to cover a wider range of service, and that the regular station officials, as well as those in charge of Climate and Crop Service centers, should have the privilege of taking part in the proceedings and profiting by the experience to be gained by future conferences of this character. Accordingly on April 5, 1898, the Chief of the Weather Bureau announced that a convention of Weather Bureau officials would be held at Omaha, Nebr., probably in July or August, 1898, and that the proposed convention would meet in place of the American Association of State Weather Services. The hope was expressed that every section director and local forecast official would be present, and that as many regular station officials and assistants as could do so would attend. This announcement was received with general favor, several from the Central Office, and nearly all of the prominent station officials expressing their intention to be present.

Brief papers on topics of interest to the Bureau, both in its practical work and upon scientific subjects, were invited, and the many valuable and interesting contributions which form a part of this report show how ready the employees of the Bureau are to respond when called upon to write upon such topics.

In the announcement of April 5 it was not possible to fix the date of the meeting, but at that time it was expected that it would be called about midsummer. Later, however, it was deemed advisable to postpone the meeting until after the close of the crop season. It was not until September 15, that October 12 and 13 were determined on as the dates of the meeting, but the uncertainty as to the time of the Convention in no way interfered with making such preliminary arrangements as were necessary, nor did it tend to decrease interest in the Convention on the part of the officials of the Bureau.

By October 1 nearly seventy Weather Bureau officials had made arrangements to be present at the Convention, authority to attend

having been granted upon condition that station duties would be performed without additional expense to the Bureau during the period of their absence, and that the journey from their respective stations to Omaha and return should be made without cost to the Bureau for transportation, personal or other expenses. That so large a number of officials should attend the Convention under these unavoidably hard conditions, is a matter which forcibly illustrates their zeal and their fidelity to the great work on which they are engaged.

The Commercial Club of Omaha kindly placed its elegant rooms in the Board of Trade Building at the disposal of the Convention, and a number of hotels conceded special rates to its members.

The Chief of Bureau appointed as executive committee to arrange such details as are incident to gatherings of this character, the following: I. M. Cline, M. D., Galveston, Tex., Chairman; Prof. Cleveland Abbe, Washington, D. C.; H. C. Bate, Nashville, Tenn.; James Berry, Washington, D. C.; F. H. Brandenburg, Denver, Colo.; J. Warren Smith, Columbus, Ohio; T. F. Townsend, Philadelphia, Pa.

As the officers of the Transmississippi and International Exposition had planned to conduct peace jubilee exercises on October 12, which were participated in by the President of the United States, members of his Cabinet, officers of the Army and Navy, and other high civil officials, among whom was the Chief of the Weather Bureau, who was to open and preside over the Convention, it finally became necessary to defer the meeting until October 13, which necessitated a continuance of its sessions on the 14th.

The various States and the District of Columbia were represented by the officials of the Bureau as follows:

- Alabama*.—F. P. Chaffee, Montgomery.
- Arkansas*.—E. B. Richards, Little Rock; Wayland Bailey, Fort Smith.
- California*.—W. H. Hammon, San Francisco; G. E. Franklin, Los Angeles.
- Colorado*.—F. H. Brandenburg, Denver; J. P. Slaughter, Pueblo.
- District of Columbia*.—Prof. Willis L. Moore, Prof. Cleveland Abbe, Prof. H. A. Hazen, James Berry, E. B. Calvert.
- Florida*.—A. J. Mitchell, Jacksonville.
- Georgia*.—J. B. Marbury, Atlanta.
- Illinois*.—H. J. Cox, Chicago; C. E. Linney, Chicago; John Craig, Springfield;
- P. H. Smyth*, Cairo.
- Indiana*.—C. F. R. Wappenhans, Indianapolis.
- Iowa*.—J. R. Sage, Des Moines; G. M. Chappel, Des Moines; E. H. Bowie, Dubuque; U. G. Pursell, Sioux City; J. M. Sherier, Davenport.
- Kansas*.—T. B. Jennings, Topeka; G. H. Noyes, Topeka; G. T. Todd, Dodge.
- Kentucky*.—G. E. Hunt, Louisville.
- Louisiana*.—A. G. McAdie, New Orleans.
- Maryland*.—F. J. Walz, Baltimore.
- Massachusetts*.—John W. Smith, Boston.
- Michigan*.—C. F. Schneider, Lansing; N. B. Conger, Detroit.
- Minnesota*.—T. S. Outram, Minneapolis; P. F. Lyons, St. Paul.
- Missouri*.—R. J. Hyatt, St. Louis; A. E. Hackett, Columbia; R. L. Anderson, Hannibal.
- Montana*.—E. J. Glass, Helena.
- Nebraska*.—L. A. Welsh, Omaha; J. H. Spencer, Lincoln; J. C. Piercy, North Platte.
- New Jersey*.—E. W. McGann, New Brunswick.

New York.—D. Cuthbertson, Buffalo; A. F. Sims, Albany; R. G. Allen, Ithaca.
North Dakota.—B. H. Bronson, Bismarck.
Ohio.—E. A. Beals, Cleveland; J. Warren Smith, Columbus; G. Hass-Hagen, Toledo.
Oregon.—B. S. Pague, Portland.
Pennsylvania.—T. F. Townsend, Philadelphia.
South Carolina.—J. W. Bauer, Columbia.
South Dakota.—S. W. Glenn, Huron; G. B. Wurtz, Pierre.
Tennessee.—H. C. Bate, Nashville; L. M. Pindell, Chattanooga; S. C. Emery, Memphis; W. M. Fulton, Knoxville.
Texas.—I. M. Cline, Galveston; H. H. Curley, San Antonio.
Washington.—G. N. Salisbury, Seattle.
Wisconsin.—W. M. Wilson, Milwaukee.
Wyoming.—W. S. Palmer, Cheyenne.

The Climate and Crop Sections were represented by voluntary observers from a number of States, as follows:

California.—N. W. Blanchard, Santa Paula.
Colorado.—P. H. Boothroyd, Waterdale; E. S. Turner, Julesburg.
Illinois.—C. N. Butt, Knoxville.
Iowa.—E. W. Calwell, Sioux City.
Kansas.—M. B. Light, Winfield; Martin Musil, Ellenwood.
Missouri.—A. J. Sharp, Harrisonville.
Montana.—M. H. Pierce, Plains.
Nebraska.—H. F. Bethune, Lincoln.
New York.—Dr. John W. Kales, Franklinville; D. M. Kinne, Hoyts Corners;
 J. Knappenburg, Mount Morris.
Oregon.—B. E. Dosch.
South Dakota.—G. A. Perle, Flandreau; Frank Williams, Centerville.

The Convention was placed under great obligations to Mr. R. M. Reese, stenographer to the Honorable Secretary of Agriculture, for his most valuable and efficient services in reporting its proceedings.

Owing to limited time it was not possible to read at the Convention all the papers presented, but most of them were read in part and are given in this report, either in full or in part, as seemed most proper. After the opening address by Prof. Willis L. Moore, Chief of Weather Bureau, the following program was taken up:

1. Relation between the Weather Bureau and the public.—F. J. Walz, Baltimore, Md.; G. N. Salisbury, Seattle, Wash.
2. Forecasts and special warnings:
 - (a) Forecasts best calculated to aid maritime interests of the Great Lakes; method of reaching those interested.—H. J. Cox, Chicago, Ill.; N. B. Conger, Detroit, Mich.
 - (b) Are the present warnings and displays by flag and lantern the best that can be devised for the Atlantic and Gulf coasts?—John W. Smith, Boston, Mass.; Alex. G. McAdie, New Orleans, La.
 - (c) Possibility of giving warnings of northers, cold waves, and heavy snows to stock raising interests forty-eight hours in advance.—F. H. Brandenburg, Denver, Colo.; E. J. Glass, Helena, Mont.
 - (d) Warnings of washouts, floods, cold waves, and heavy snowfalls for the benefit of transportation companies.—J. Warren Smith, Columbus, Ohio; T. S. Outram, Minneapolis, Minn.
 - (e) What classes are most benefited by the forecasts? Are they just what are needed? Are they properly disseminated and utilized?—J. R. Sage, Des Moines, Iowa; H. C. Bate, Nashville, Tenn.
 - (f) Long range forecasts: Can they be made with sufficient precision to be of general utility?—Prof. H. A. Hazen, Washington, D. C.; Patrick Connor, Kansas City, Mo.; B. S. Pague, Portland, Oreg.
 - (g) Forecast distribution: Should the wording of the forecasts be confined to the vocabulary of the present logotype outfit? Is it advisable to extend

- the vocabulary of the logotype outfit?—F. P. Chaffee, Montgomery, Ala.; G. M. Chappel, Des Moines, Iowa.
- (b) River and flood service.—R. J. Hyatt, St. Louis, Mo.; L. M. Pindell, Chattanooga, Tenn.
- (c) Should warning messages (Form 1043 C) be of some distinctive color to more readily attract attention?—S. W. Glenn, Huron, S. Dak.; T. B. Jennings, Topeka, Kans.
3. Paper: Relation of the Weather Bureau to the Department of Agriculture.—E. B. Calvert, Washington, D. C.
4. West Indian hurricane service.—Prof. Willis L. Moore, Washington, D. C.
5. Possibilities of the weather service on the Pacific coast. Value of Mount Tamalpais observations.—W. H. Hammon, San Francisco, Cal.; B. S. Pague, Portland, Oreg.
6. Paper: Some rain-producing processes.—Prof. E. B. Garriott, Washington, D. C.
7. Relations with the press, commercial bodies, and scientific organizations. How promoted.—E. A. Beals, Cleveland, Ohio; A. F. Sims, Albany, N. Y.
8. Meteorological statistics: How to improve them that they may meet the needs of the medical profession, hydraulic and sanitary engineers, promoters of irrigation projects, etc., and does the present monthly section report meet such needs?—W. M. Wilson, Milwaukee, Wis.; E. W. McGann, New Brunswick, N. J.
9. Paper: Some notes on agricultural meteorology, with special reference to the rainfall element.—Charles E. Linney, Chicago, Ill.
10. Effect of forest clearing and cultivation upon: First, water supply and soil; second, rainfall; third, temperature.—W. M. Fulton, Knoxville, Tenn.; Geo. N. Salisbury, Seattle, Wash.
11. Is the weather map appreciated and understood by the masses? Would not the postal card weather forecast prove a satisfactory substitute for the map, except where it is used for the purposes of study and instruction?—E. B. Calvert, Washington, D. C.; T. F. Townsend, Philadelphia, Pa.
12. Paper: Primary work on meteorology for the use of schools.—Patrick Connor, Kansas City, Mo.
13. Should not certain important Weather Bureau stations, the duties at which cover a wide range of work, be designated stations of instruction for newly appointed observers?—J. Warren Smith, Columbus, Ohio; C. F. R. Wappenhans, Indianapolis, Ind.
14. Climate and Crop Service, weekly bulletins: Should remarks of correspondents be published as supplementary to general discussion? Should weekly reports of temperature and rainfall be telegraphed to section centers from selected voluntary stations?—A. E. Hackett, Columbia, Mo.; J. B. Marbury, Atlanta, Ga.
15. Paper: Frost fighting.—Alex. G. McAdie, New Orleans, La.
16. Aerial observations.—J. C. Piercy, North Platte, Nebr.; G. B. Wurtz, Pierre, S. Dak.
17. Should not a book providing for permanent record of meteorological observations for prolonged periods be furnished for use of section centers and voluntary stations?—J. W. Bauer, Columbia, S. C.; G. A. Loveland, Lincoln, Nebr.
18. Paper: Atmospheric moisture and artificial heating.—W. M. Wilson, Milwaukee, Wis.
19. Should not a book be provided suitable for keeping record of the issue of instruments and flags to voluntary observers and displaymen?—R. G. Allen, Ithaca, N. Y.; B. H. Bronson, Bismarck, N. Dak.
20. Are changes in the present forms (1053 and 1054) for reporting weekly climate and crop conditions advisable?—Charles E. Linney, Chicago, Ill.; A. J. Mitchell, Jacksonville, Fla.
21. Should pay be allowed persons, not in the employ of the Bureau, while learning station duties to enable them to properly perform such duties in emergencies?—D. Cuthbertson, Buffalo, N. Y.; G. E. Franklin, Los Angeles, Cal.
22. Papers:
- Professor Marvin's weighing rain and snow gauge.—W. W. Carlisle, Minneapolis, Minn.
- Interchange of standard climatic data.—Alex. G. McAdie, New Orleans, La.
- Studies of climate.—F. J. Walz, Baltimore, Md.
- Voluntary stations, their object and collateral functions.—A. J. Mitchell, Jacksonville, Fla.
- Snow and ice measurements.—Hermann Volker, St. Paul, Minn.
- Benefits of the Weather Bureau to western Nebraska.—J. C. Piercy, North Platte, Nebr.

Development of the Weather Map.—E. B. Calvert, Washington, D. C.
 Establishment and inspection of voluntary, river, and cotton belt stations.—
 J. B. Marbury, Atlanta, Ga.
 Storm signals on the Great Lakes.—H. J. Cox, Chicago, Ill.
 Long-range weather forecasts.—A. B. Crane, Pensacola, Fla.
 The weather as a topic of conversation.—A. S. Brendle, Schaefferstown, Pa.
 Distribution of forecasts by mail.—P. F. Lyons, St. Paul, Minn.
 Utility of hygrometric observations.—A. Pennell, M. E., Kansas City, Mo.
 Wind vanes.—C. P. Cronk, Cape Henry, Va.

OCTOBER 13, 1898: MORNING SESSION.

The Convention was called to order at 10 o'clock a. m., in the rooms of the Commercial Club of Omaha, by Prof. Willis L. Moore, Chief of the Weather Bureau, who said:

GENTLEMEN, OFFICIALS OF THE UNITED STATES WEATHER BUREAU: I am very glad to have the opportunity to welcome you here this morning; to welcome men who are not only interested in meteorological science, but in applying that science to the commerce and the industries of the United States. That they are willing to come here and give their time and pay their own expenses for the purpose of communicating one with the other—the State of Washington getting information from Florida, and New England from the great arid Southwest—shows that you have such heart in this work that you are willing to sacrifice your own personal interests to the public weal. I remember the first convention I attended; it was a number of years ago, when I was a section director. Afterwards, when I came to the control of the weather service, I found that the discussions which I had heard at Buffalo and Indianapolis had given me many useful ideas. Many of these you have since seen incorporated in the rules and regulations of this service. Now, we have met again, and our numbers are much greater than at any previous meeting. We meet under slightly different conditions—simply as Weather Bureau officials. Before, we met as representatives of State organizations, or as representatives of State organizations having cooperation with the Federal service. Such cooperation has in great measure been succeeded by the Federal Government taking complete control of what were the State services, although in a few cases there remains very valuable cooperation between the National service and the State services, as in New York, Iowa, New Mexico, California, Maryland, and Michigan.

I shall not take up your time this morning with a long address, for I know we have an extensive program. I feel, however, like taking advantage of the opportunity to discuss here a few family matters. Actions speak louder than words; therefore, I do not know that it is necessary for me to say much. I believe you all recognize the fact that to-day every man in this service, from the humblest to the most important official, stands purely and simply upon his own merits. I believe you realize that there has not been a

selection, a promotion, or a reduction in the Weather Bureau during the last several years that was not controlled absolutely and entirely by the merits of the man, without regard to extraneous influence, so far as the head of the service was able to judge. If an error has been made, it was simply an error of judgment. We are most fortunate in having had in a former Secretary of Agriculture a man who had our technical workers classified. We are still more fortunate in having for the present Secretary of Agriculture a man who, without exception, has demanded that every recommendation coming to him from the weather service shall be based entirely upon the merits of the man and the needs of the public service. We have a man at the head of the great Department of Agriculture whose innate kindness of heart is such as to warm every man's affections toward him. He has done much for the weather service; he has done more than any other man to raise the standard of its personnel. After several trips through the country, meeting with our local forecast officials, our section directors, and our observers, he came back and told me he was very much impressed with the character of the officials of the weather service, and it would give him pleasure to honor my recommendations for such reasonable advancement of these officials as the appropriations would allow him to make.

I wish to speak especially of one matter which I believe is important in maintaining a kindly yet thoroughly efficient discipline at your stations. I speak of this after extensive experience of my own, in control of some of the large stations, and especially since I have presided at the Central Office in Washington. It is this: Allow no man associated with you to come to you with tales of another, or to impeach in any measure the official integrity of his companions, unless you bring in the accused man also, and give him full opportunity to answer his accuser. Do this and you will find that the harmony and efficiency of your stations will be greatly improved. We desire to place every official, both at the Central Office and throughout the extensive ramifications of this service, in such position that he can feel that he may go on with his work without fear of his reputation or standing being assassinated. I especially call your attention to this feature. I do not know that it is necessary, because I feel that your discipline to-day is of a very high standard of excellence. And when I say discipline, I do not mean harsh treatment, or that rigid lines be drawn upon a man, but I mean such discipline as will encourage the pride of the man and the spirit of the official, and yet maintain the authority of the officer in charge. It is possible to have such discipline, and I believe we have it to-day. I can say further that there are no dissensions at the Central Office of the Weather Bureau. There is harmony there, and that means much to the rest of you.

I would encourage all to be students. I know that most of you are, and I know that many (myself included) have found the best years of their lives for study while in the weather service. The Central Office has outlined a course that we expect every new appointee to become proficient in before he is eligible for advancement. It is necessary, in writing your reports, that you express yourselves in good English. It is necessary that the local forecast official be well versed in physics and mathematics. It is necessary that the section director be thoroughly conversant with the processes under which plant life has its inception and makes its growth. We scrutinize carefully the qualifications of a man, his education, moral character, and the study he has made since entering the service, before we take him up for advancement.

Just one more matter. We have made many changes in the distribution of the salary fund. A few employees have lost thereby while many have gained. We have endeavored to so apportion the fund as to make the pay commensurate with the importance of the assignment and the merit of the official. I believe you are satisfied that there has been a determination at the Central Office to so reapportion that fund as to secure a more equitable distribution of the money than had obtained before.

I think it but proper to take advantage of this occasion to refer to an official, not now associated with us, who spent more than twenty-five of the best years of his life in the work of this Bureau. When hostilities with Spain began he returned to the Signal Corps of the Army, to which branch of the military service he belonged. I am sure you join me in wishing him a brilliant career. I allude to Col. H. H. C. Dunwoody.

Before proceeding to the consideration of the program, I would say that away back in 1870 there was one who is with us to-day, who laid the foundation of the present weather map, and who, by his own investigations and experimentations, compiled weather charts and made forecasts long before the Federal Government did so. That man has been connected with the Federal Weather Service from the very day of its beginning, and has been an important worker through its whole development. He is a man whom every one of you honors for his scientific attainments, and whom all who know him esteem for his courteous bearing and innate kindness of heart. I shall ask Prof. Cleveland Abbe from time to time to relieve me as presiding officer of this Convention.

Professor ABBE. Gentlemen, I think you all want to get down to business, and you don't want to hear from me. I have been writing a good deal the last five or six years in the Monthly Weather Review, and you know just what I would say if I were to say it all over

again. The Chief wants to get through with this long program. How he is going to do it, I don't know, but we will begin with paper No. 1.

TOPIC No. 1.—RELATION BETWEEN THE WEATHER BUREAU AND THE PUBLIC.

F. J. WALK, Baltimore, Md., and G. N. SALISBURY, Seattle, Wash.

MR. WALZ. It embarrasses me somewhat to have the first paper on the program, especially as I am to immediately follow our eloquent and honored Chief in addressing you, and also because this is my first attempt at speaking to so large a body of my colaborers. I am still more embarrassed by the fact that while en route, the few notes I had made on the subject of this first topic were lost, and so I shall have to depend upon the inspiration of the moment, aided by the few notes I have since jotted down, and by your inspiring presence.

The topic is, The Relations Between the Weather Bureau and the Public. This subject is one practically without limits, were it proposed to discuss it in all its phases and features, for all our work is along this line. All mankind is affected by the weather in some of its phases, and it is the intent and purpose of the Weather Bureau to study out those phases and consider them in all their various aspects. Even if we take any one of several lines which might be suggested, it would take up the entire time of this Convention. The subject is one with which all the officials here assembled are daily confronted in the management of their stations; it is one of the most important subjects we have to deal with. The value and importance of each local office depends so largely upon the handling of these questions that one might say the prime object of this Convention is to consider the relations between the Weather Bureau and the public in some one or all of their phases. Nearly every paper that will be produced, and nearly every discussion of importance that is to be brought out, will be in the line of looking for some improvement in our relations with, and of giving more benefits from, the Bureau to the public. The propositions I shall suggest will bear more directly upon those subjects which have been made manifest in the management of local offices. In a general sense these relations might be considered under two heads—the direct relations we have with the public, and the indirect. And again we might classify the public under two heads, as the general public who want to look at a forecast to see what the weather will be to-morrow, and the commercial and maritime exchanges and organizations of that kind, upon whose dealings the weather has a direct effect, and this not only one day, but day after day, year in and year out. Under this latter head we might classify the relations we have with schools and various educational institutions. The direct kinds of relations, I might say, are those that exist between the personnel of the station and the public. The value of the mental, moral, and social qualities of the official in charge determines, to a very large extent, the value of a station to the public. The mental qualifications of the officials you will of course have to take for granted after having heard what our honored Chief has said;

and judging from his attitude toward the moral status of our stations, any agitation on that question would be rather superfluous. The social qualifications are of considerable importance. It is now within the power, as unfortunately it once was not, of every member of our body to become a representative man in his community, and he owes it to himself and the Bureau that he should not be satisfied with anything short of that. He should be a representative man, one who is looked up to, so that anything he may say will have weight attached to it because of his being a representative man.

Then, again, in our direct personal relations with the public, the location of the office is a very important matter. The office, as we all know, should be centrally located and easy of access to the public; it should be where the public can come into close contact with us, and where the men engaged in the interests to be served by us can visit the station and become more familiar with our work; the benefits to be obtained from this personal intercourse are almost incalculable. There should be frequent personal visits by the official in charge to the various organizations, maritime exchanges, boards of trade, etc., and they should know us and our work, and be interested in it, as indeed they are. The Weather Bureau official should be familiar with the needs of organizations of all kinds, and provide for them—not only their present needs, but by anticipating their wants. He should acquaint himself with the public school system; induce, as far as possible, an interest in the study of meteorology and meteorological subjects, elementary, it may be, but sufficient to enable every one of the rising generation to take an active interest in our Bureau, and be able to read a map intelligently and make his own deductions therefrom.

Indirect relations are maintained through the issue of our local publications, through the medium of the press, and through substations, voluntary observers, and the distribution of forecasts. The best methods to be followed in the issue of our publications, whether they are at present such as we want them to be, or whether they need modifications, will probably be discussed in papers that will follow. The local newspapers, however, as we all know, should be utilized to the fullest extent in the dissemination of whatever information we may have to give to the public, not only meteorological data, but information as to our plans for future extension of the benefits of the weather service. I think the newspapers should be advised of these matters in advance, so as to be able to tell the people of anticipated changes. The establishment of substations and the serving of outlying interests call for special study. Officials should be as alert to the needs of distant substations, and as desirous to serve them promptly and accurately, as they are to serve those with which they come more directly in contact. Some of us are at times liable to forget the Weather Bureau's benefits are not only for those we see immediately around us, but extend far out into the State, and over the whole of it. Every day there are people far distant from us, whom we have never seen, who are looking to us for information, not only forecasts, but for the other data we have to give. We should see to it that they obtain all the information possible to give them as to our work, which they desire, and which it is possible to give them.

All of these questions will be considered, and many of them dis-

cussed during the present meeting, as well as many points I have not mentioned. We have all had our experiences, all have our cherished plans and theories, and now is the time to bring these out and have them tested, and such as stand the test of this Convention should become common property for the benefit of all of us. But we must all remember that however admirable a plan we may have, its success will depend very largely upon the personality and energy of those to whom its consummation is entrusted. That will always be the important factor in the relations between the Weather Bureau and the public.

Mr. SALISBURY. Faster and faster, more and more constantly, is the Weather Bureau and its work coming into public notice. More and more are the general public, even those of only ordinary education and intelligence, becoming quite familiar with what the Bureau does, and what it aims to do. And to-day, the modest Weather Bureau official is taking a better place among his fellow-men, and is looked upon with more confidence and respect than ever before. The foregoing are facts, for which there are good and sufficient reasons. As, since creation dawned, there never has been a time when there was no weather, so there, perhaps, has never been a time when there was not a weather prophet. Undoubtedly primitive men had their weather signs or prognostics; savage and barbaric people have in all known times had their "rain doctors;" more modern times and peoples have had their almanacs, which contained "long range" predictions; but only within a short time has meteorology become truly a science—only within half a life-time have there been organized weather bureaus, worthy of the name, for the benefit of the public. For a far longer time, to be sure, climatic records have been kept, which were very accurate, valuable, and useful, but an organization for keeping climatic records is not properly regarded as a weather bureau unless it foretells storms and weather changes.

What is the attitude of the public toward such an organization? We know how the superstitious savages have regarded their "rain doctor" with awe and amazement, not unmixed with fear or distrust. Should, unhappily, the doctor's false pretensions be exposed, woe to him. Our dethroned deities always suffer worse than common clay. Our almanac maker fared somewhat better. Credulous belief and wild wonder, or on the other hand, doubt or ridicule, were his portion. The prognostics by the moon, the sky, or animate nature, the blind guesses or absurd astronomical pretensions of the almanacs had so long held sway that the public scarcely knew how to take it when a Government service undertook to forecast storms and daily weather changes from laws so recently discovered that they were entirely unknown to the many. Some scoffed, some ridiculed, many wondered, all more or less doubted, for it was an experiment. To the uninitiated the Signal Service seemed a mystery, and indeed it was in some respects an enigma up to its last day. The curious public were, however, great investigators, and gradually the mystery lessened. It was seen that the Signal Service officials were even as other men, as far as their restrictions allowed them. Incited to read up on meteorology or weather and storm movements, becoming familiar with barometers and thermometers, the glamor of erudition that had encompassed the service became dim and shadowy. The

elaborate predictions that emanated from the chief office were seen to be deductions from general facts. The Government institution simply had at its disposal a vast electric telegraph system for instantly collecting a great number of those facts.

Though the ridicule in some instances remained, yet the general confidence grew; grew with every triumph scored by the Signal Service; grew when its storm-warnings saved hundreds of ships from peril and disaster; grew when its cold-wave warnings gave two to three days' notice of severe cold spells; grew with every successful flood warning or frost warning. The public became unsparing when marked failures occurred, with seemingly little excuse. It was generous, perhaps to a fault, where there was some excuse.

The Signal Service did a great work as all must admit, and no matter how we may view its military régime, it should never be forgotten that its officers and men worked out, in a great measure, the systems which make the weather service of this country unequaled, or even unapproached by any other. But, though doing a great work, it was not best adapted for that work, as we now well know. It had a military machinery which was supposed to greatly aid it, and by some was regarded as indispensable, but as a weather service it was sorely handicapped, for it carried ever on its shoulders (like Sinbad) a burden which would not be shaken off. The public was not *en rapport* with it; it was harrassed with a sense of exclusion; in short the military engine was not adapted to civilian work. The service and the public both realizing this full well, a simultaneous effort was made in its last days, though on opposing lines. From within its liberal minded officers strove to adapt its machinery to business purposes, and educate the public to its workings; from without the public sought to effect a transfer to a civil department. Happily the latter effort was successful. Since its organization as a civil bureau, under an appropriate department, the most liberal policy has prevailed, and every effort has been made to improve its methods, perfect its workings, and make it of the utmost possible benefit to all trades, all professions, all classes.

Hence, as officials, it may greatly profit us to consider at times how the Bureau now stands in the estimation of the public, and to reflect on these questions: What are we doing for the people; how are we doing it; is it of benefit to them; what is the popular verdict?

It is safe to attempt to reach the public expectation, for that is now high. Only sometimes it expects impossibilities. For instance, to expect to receive a forecast for a date a week ahead, or even two days, often is unreasonable at the present stage. "There may come a time," but the time is not yet. To expect to know just the hour it will begin raining is to demand a little too much; likewise, just when it will stop; just how cold it will get, and how long it will remain so.

But the public rightly expects accuracy, so far as the information goes. Inaccurate information is worse than none. It is much better to say "We do not know," however humiliating the confession, than to predict what will not come to pass. If we do not know, with considerable certainty, what the weather will be two or more days in advance its prediction should not be attempted. It savors of charlatanism; it begets lack of confidence in us; our information becomes unreliable, and whom can we blame save ourselves, if we

suffer the odium or oblivion assigned to all false prophets? The aim of the Bureau should be to foster public confidence. It should always be sure of its ground. Even the humblest officials should ever remember, and the more prominent ones should never forget, that each correct statement and each accurate prediction adds to the grandeur and beauty of its temple of reputation; while every misstatement, and every gross failure, is a stone taken from its foundation, lessening the stability and threatening the overthrow of the structure.

"England expects every man to do his duty" signaled a great admiral at the beginning of a great battle. Our service and an indulgent but just public expect this of us. The commercial and scientific bodies, representative men, have always treated the local officials with every consideration due to men of culture and intelligence. In so doing, while honoring the Government Bureau, they reflect credit on themselves. We should never prove unworthy of it.

The general public, all classes and conditions, meet in our offices every day. We give them all kinds of information, always cheerfully and courteously let us hope, and they appreciate it, or ought to. Our information must be exact, and given clearly, in such a manner as to inspire confidence, if we wish it to do good. They have the right to expect it of us. They may not have the right to annoy or bore us, but should some do so it would hardly be advisable to tell them of it.

In its relation to maritime interests the Weather Bureau has one of the greatest responsibilities. True, calamitous storms causing disaster to shipping are infrequent, but it is necessary to tell just when storms will be violent. In consequence of stormwinds being so uncertain it is sometimes thought necessary to warn of all storms in order that the violent ones may not be overlooked; therefore, business interests are often put on the lookout for severe storms which do not materialize and a loss of confidence results, the natural inference being that the warnings were mere guess work and need not again receive serious attention. This is a grave mistake on the part of the affected interests, and a fatal day comes when it is seen and bitterly rued. How can greater confidence be engendered, or rather how can loss of confidence be prevented? Manifestly by accurate diagnosis on the part of officials, so that distinction will be made between slight and dangerous storms. This is very difficult and leaves the possibility of a storm proving more violent than appearances indicated. It may be that eternal vigilance is the price of security, as of liberty, but it is impossible to keep the interest up to a high pitch all the time by constantly sounding the warning of danger when no danger appears. And yet there are times in certain localities when storms follow in such rapid succession that to give warning of all requires an almost constant signal. Therefore, I believe it imperative that a method to distinguish between the approach of a harmless storm and a disastrous one be found. Often the fault is with the conditions, rather than with the service. Ships should be built to withstand the fiercest gales; anchor chains should hold against the greatest possible strains; wharves should be strong enough to endure the heaviest waves; dike and sea walls should be high and thick enough to turn aside the highest hurricane tides. But in this day and generation the ordinary is built for and not the ex-

traordinary. Take the case of Savannah, Charleston, and other cities of our south Atlantic coast. Every three to five years disastrous West India hurricanes approach them, causing widespread destruction and loss of life; yet what steps are taken to provide more secure anchorage, to erect stronger structures, to provide dikes and sea walls for the tideswept islands? Here the communities are plainly at fault, and not the bureau. If everything was kept strong and secure, then, as I have suggested, the minor storms might safely be neglected.

There is no doubt that the agricultural class is now coming into close relation with our Bureau, and that in certain branches of agriculture considerable benefit is derived from our work. The writer has ever held the opinion that the greatest benefit of the weather service to agriculture would be in a climatic way; ascertaining what portions of the country could be successfully cultivated. In collecting this climatic record the voluntary service is doing a great work, stupendous in magnitude and far-reaching in results. It is establishing a climatic history and character for each locality that will be a guide to all future generations. Its value to the general government in thus indicating the capabilities and limitations of those localities will be beyond price. Yet it is obtained at very little expense so far as concerns the voluntary observer. It is possible that the daily forecasts, now of value to certain classes of farming, can be so extended or their distribution so improved as to reach many more classes. It is a fair conclusion, however, and there are many who hold it, that a large portion of farmers will continue to farm according to their lights and not according to the advice of the Government Weather Bureau; this, too, while not denying that the successful cranberry grower of Wisconsin is the one who relies on the prediction to warn him of frost and the successful raisin grower of California is he who heeds the Bureau's rain warnings.

The press is and must ever be the medium through which the greatest amount of our information reaches the public. Consequently, it behooves us, as officials, always to be on good terms with the editors and reporters. Most of us are, though at times it requires considerable tact to steer clear of dissension and much patience under frequent nagging and senseless though not ill-meant witticisms. Some papers will persist in being cold, if not secretly unfriendly. The local official should carefully win them over. Nothing is ever made by antagonizing a newspaper, and much may be gained through its friendship, not only by the official, but much more by the service he represents.

In regard to the possible future of the Bureau, we can not lift the veil, but can only see dimly through it, as we judge the future by the past. Who, thirty years ago, would have thought the present development of the Weather Bureau possible? Did the public realize what value its records, its daily forecasts, its storm warnings would prove to be? Assuredly not. So we can not set a limit to the possibilities of the service for usefulness. It is covering a wide field, but not too wide. Year by year the experience and knowledge of former years is built upon, and future research and discoveries will most surely add vastly to our present knowledge of meteorology and our usefulness to the public.

Professor MOORE. Mr. Salisbury has spoken of the Signal Corps. I had some conversation with General Greely yesterday, and he asked me especially to present his compliments to this Convention. I was anxious that he should be here and speak to you, but he said that he appreciated the fact that we would be glad to have him here, and he would be here if he had not made engagements that would prevent him from attending. I want to say to you that in the closing hours of the last Congress there was repealed that part of our organic law which permitted the Chief Signal Officer, in addition to his military duties, to take charge of the Weather Bureau, and likewise appoint four army officers to act as assistants. Now the repeal of that law was favored by General Greely, the man directly interested. In appearing before the Senate committee I held in my hand a letter from General Greely, saying that the weather service had demonstrated its ability to handle this extensive public service under a civil administration, and that it was time the Bureau was relieved from the possibility of army control; that he believed the Signal Corps, of which he was Chief, would be better off in confining itself to its purely military functions; that his officers would know where they were to make their records; that his bureau would derive benefit from confining itself purely to its military work, and the Weather Bureau would receive equal benefit by having its perpetuity under civil control assured to it. We are under obligations to Gen. A. W. Greely, than whom no abler Chief ever presided over the weather service, for his manly and magnanimous action.

Mr. McADIE. In view of what the Chief has said, I think it would be a graceful thing to send a greeting to the Signal Corps, United States Army, and General Greely, its chief, expressing our admiration and appreciation of the splendid work done by that corps under his command during the war. We are proud, I think, of our old corps. I, therefore, move the following resolution:

Resolved, That the Weather Bureau officials, in convention assembled, express their appreciation and admiration of the excellent work done by the Signal Corps, United States Army, during the late war.

This was adopted unanimously by a rising vote, and the Secretary directed to forward a copy to the Chief Signal Officer, United States Army.

Professor MOORE. In Mr. Walz's paper I notice he referred to the personal character of the man—his moral character and social standing as a representative of the Weather Bureau. He passed it rather lightly, but it is an important matter. We have made it the subject of inquiry whenever selecting section directors or local forecast officials, and I mention it now because our right to make such inquiry has been questioned; it was several times questioned whether we had the right

to inquire into the moral character, the domestic and personal relations of a man, before selecting him for an important trust. I believe we have that right, and I believe we shall always assume the right to make such inquiries regarding a man. Not only must he be an able official, if he is selected for an important trust, but his private character, his moral and domestic relations, must be clean. (Applause.)

TOPIC No. 2.—FORECASTS AND SPECIAL WARNINGS.

(a) *Forecasts best calculated to aid maritime interests of the Great Lakes; method of reaching those interested.*

H. J. Cox, Chicago, Ill., and N. B. CONEY, Detroit, Mich.

Mr. Cox being indisposed, his paper was read by Mr. Palmer, of Cheyenne, Wyo., as follows:

Not long ago masters of vessels on the Great Lakes pretended to disregard the forecasts and storm warnings of the Weather Bureau. Gradually the wants of the merchant marine have been more clearly made known, and efforts have been made to render the forecasts of the greatest practical value. At the opening of navigation last spring the plan of sending daily forecasts of wind and weather to all lake ports was adopted. This new service, together with the issue of the monthly lake marine meteorological charts and the work incidental thereto, comprise the greatest improvements during the past year. It is my opinion that lake forecasts should have special reference to the 24-hour period, and should be extended further only when, in the opinion of the forecaster, they can be made with a fair degree of accuracy.

The knowledge of the probable force and direction of the wind is of greatest importance to owners, navigators, and shippers, and also whether the weather is going to be thick with rain, sleet, snow, or fog, particularly the latter two. While the occurrence of fog may be expected under certain typical conditions, it also occurs under other and different conditions which are not understood. On this account, forecasts of fog have been rarely attempted, but it is possible that through the investigation now going on information may be secured which will lead to successful forecasts of the foggy condition that is so dangerous to shipping interests. During the prevalence of fog sailors may proceed with a fair expectation of avoiding accidents while "in the open," but progress through channels is always attended with the greatest danger. While daily forecasts are of great value, ample warnings of severe storms must be given in order that measures may be taken to prevent loss of life and property. The velocity of wind in a gale does not in itself show the real danger to navigation in any particular locality. In every case the *direction* is a most important factor. Along the south shores of Lakes Superior and Erie and at the southern ends of Lakes Michigan and Huron a northerly wind of 35 miles after four or five hours duration prohibits navigation, while a 45 or 50 mile wind from the south causes no interference whatever. During the southerly gales of September 21, 1893, when the wind

attained a velocity of 60 miles per hour at Marquette, Mich., shipping along southern Superior suffered no inconvenience, although a 25-mile wind from the north after a few hours often stirs up such a sea as to force vessels like the *Northwest* and *Northland* to seek shelter in some one of Lake Superior's harbors. In fact, it is probably the effect of the sea rather than the direct effect of the wind itself which causes so much trouble. A captain can proceed along the leeward shore in absolute safety, when it would often be impossible for him to make any headway on the opposite side of the lake. Consequently, in issuing storm warnings for different points the probable direction of the wind should be taken into consideration in every case and no storm warning should be sent to any place unless the expected high velocity and direction represent a wind actually dangerous to navigation in that locality. The weather information can be distributed to the shipping interest by means of the press, telephone, telegraph, weather map, storm-warning bulletin, storm signal, marine reporter, and lake marine mail. While the telegraph must be used by the forecast center in notifying displaymen, the most rapid and effective mode of local distribution is by the telephone. Through that agency the Chicago weather office is often able to disseminate a storm-warning message to more than one hundred points in the city within a few minutes.

Mr. CONGER. The subject which has been assigned me at this time is one that requires much thought. Constant attention to the marine interests of the Great Lakes alone will enable us to arrive at a satisfactory conclusion as to the best solution of our problems. In order to make our meaning more plain we shall be compelled to delve into ancient facts and recent history, and show the immense importance of the traffic on these inland seas. I trust you will bear with me in the somewhat dry figures that will be used to indicate the value of the shipping and the number of lives that the vessels carry, all dependent on the careful watchfulness of the Weather Bureau.

There are many at this Convention who probably are not familiar with the shipping of the Great Lakes or with the class of tonnage that floats on the broad bosom of these mighty fresh water oceans. For your information it may be stated that more tonnage passes the port of Detroit annually than the combined tonnage of our Atlantic, Gulf, and Pacific coasts. There are passenger steamers plying on these waters finer in their equipment than any ocean steamer afloat at the present time. These particular steamers are exclusively for passenger traffic, and do not carry a pound of freight during the season they are in commission. We may call attention to the steamer *Christopher Columbus*, the great whaleback passenger steamer, the like of which floats on no other body of water. It may be stated that during the busy season of the year an average of 100 vessels pass Detroit every twenty-four hours, or one every fourteen minutes; for twelve hours there have been 84 recorded passages, and for one hour a maximum number of 57, making the average nearly one every minute.

Of the large freight boats now plying on the Great Lakes, two representative fleets may be mentioned: The Pickands, Mather Company's fleet of fifty-one vessels, which is the largest fleet handled by an individual firm, and the Bessemer Steamship Company's fleet,

which represents the best type of the largest freight boats floating on the lakes at the present time.

The Pickands, Mather Company's fleet consists of 21 steamers and 30 barges, which are used principally to carry iron ore from the head of Lake Superior to either Lake Michigan or Lake Erie ports.

If this entire fleet were placed bow to stern it would make a line of vessels 3 miles long, and if loaded with ore would carry at one time 184,300 tons; the valuation of the vessels and cargo would amount to nearly \$7,200,000; this immense cargo, if loaded on ore cars for shipment to the smelting furnaces, would require 6,143 cars and would make a train 42 miles long. It takes 572 persons to make up the crews of this fleet.

The Bessemer fleet contains among its vessels the largest steamers and the largest barges, and is representative of the higher class of freighters at the present time. The steamer *Samuel F. B. Morse*, launched this season, is 476 feet over all, 50 feet beam and 30 feet deep. Her capacity on 17 feet mean draft is 6,000 gross tons of iron ore, 225,000 bushels of wheat, or 430,000 bushels of oats. She has quadruple engines of 2,700 horse power. On a recent trip with a slow running wheel she made 14½ miles per hour light, and 13½ miles loaded. With a fast running wheel she is expected to make 17 miles per hour light. She has four Scotch boilers 13½ feet in diameter.

The barges *John A. Roebling* and *John Fritz* are twin ships. They are each 456 feet long over all, 50 feet beam and 29 feet deep. Their capacity is 7,000 gross tons of iron ore on 17 feet mean draft, or 260,000 bushels of wheat or about one-half million bushels of oats. It should be stated in connection with the *S. F. B. Morse* that she was intended to tow the *Roebling* and possibly the *Fritz* also, so that these three boats would move 20,000 gross tons of ore and nearly three-quarters of a million bushels of wheat and a million and a half bushels of oats. There are in this fleet 21 ships in all, 17 of which have a capacity of upward of 5,000 gross tons. The 21 ships will carry about 105,000 gross tons per trip. With fair dispatch twenty trips per season can be made, loading only one way, carrying somewhat more than 2,000,000 gross tons. Loading both ways they will carry about three and a quarter to three and one-half millions gross tons, or upward of 70,000,000 bushels of wheat in a season. Allowing 20 bushels of wheat to the acre this fleet would carry the product of 3,500,000 acres of land and would supply every man, woman, and child in the United States with a bushel of wheat. The crews average 24 to 25 men each. The cost of this great fleet was about \$4,000,000, and it will carry between \$5,000,000 and \$6,000,000 worth of ore during one season, loading only one way.

When the Signal Service was first organized in 1871, the class of tonnage was very much smaller, in fact up to 1874, according to Beeson's guide of vessels now afloat, there was not a single vessel that would register 1,000 tons, and only one between 1874 and 1880 that registered over 1,000. The great increase in size of vessels began about 1887, and this increase has continued until the present year when the maximum was reached in the construction of the *S. F. B. Morse*, the *Roebling*, and *Fritz*.

The large tonnage floating on these great bodies of water requires to be well looked after by the Bureau, which is by law assigned to this particular work; and therefore I desire to call attention to certain

points which have impressed themselves on me during my experience on these lakes.

The forecasts best calculated to aid maritime interests on the Great Lakes are those which give the latest information about storm movements, and must issue from experienced forecast officials, who thoroughly understand the conditions they are endeavoring to meet. It is important for the forecast official to know the localities for which he is issuing the warnings, in order that they may be of the most service to them. For instance, high south winds are not dangerous on the south shore of Lake Superior, but it is next to impossible to put this information where it will be of service to the navigators who are on the fairway between Whitefish and Keweenaw points. Vessels leaving Marquette with a south gale simply keep along shore and in comparatively smooth water. The reverse is serious, as northerly gales cause damage along the entire southern shore of this lake. Again, on Lake Erie, southerly gales—that is, from the southeast or south—are of no serious import, but when the wind shifts to the southwest, then trouble begins and masters are on the lookout. South-shore Lake Erie ports are easily entered with south winds, but with southwest to north winds it is difficult to make an entry into these harbors, as most of them have narrow openings between piers to the inner harbor. For this reason southeast signals should not be displayed on Lake Erie, but an advisory message should be sent instead. In the record of twenty-six years and of over sixty-five southeast signals ordered at Detroit, only five have been verified by high southeast winds. Now, on the east end of Lake Ontario the southeast signal has great importance, as tow barges leaving the St. Lawrence River for Oswego encounter very heavy seas from southeast gales, and in consequence are obliged to lay to at Cape Vincent.

Southeast gales are not so serious on Lake Huron as are those from a northerly direction. Brisk northerly winds for some hours will cause more vessels to seek shelter on the southern end of the lake than a heavy southwest gale. One point in the displaying of signals I would desire to impress on all who have occasion to forecast for the lakes, and that is, an easterly signal should not be displayed when it is anticipated that the wind will shift to the westerly before the expiration of the time limit. I mean that a southeast signal should not be displayed when it is expected that the wind will shift to the southwest or west before the expiration of the 24-hour period. In using the terms "easterly" and "westerly" signals, I mean northeast to southeast for "easterly" and southwest to northwest for "westerly." On all the lakes the shift of the wind from east to west quadrants is of great importance, and it should be the object of the forecast official to anticipate this change. The forecast official has in his hands the power to anticipate these changes, which are of great importance to the maritime interests of the Great Lakes. He can call for special observations whenever, in his judgment, they are needed. When a storm is advancing across the lakes, these special observations are vitally important in assisting to anticipate the wind changes, and I believe it good policy to make free use of the telegraph during the time signals are displayed. It would be much more effective to hoist a southwest storm signal instead of southeast should it be apparent that the wind will shift to the southwest before the expiration of the time period. That the gale will set

in first from the southeast and then shift to the southwest should be incorporated in the message ordering the signal. It is the duty of the forecast official to anticipate the shift of wind, and not wait until the shift has arrived and then change the signal. Masters of vessels have commented on this delinquency on the part of the Bureau, and in doing so indicate that the Bureau is slow to act.

During the time period the forecast official should be allowed to change the signal from one direction to another, and this change should not affect his verifications. The changing of the signal from northeast to northwest should not affect the northeast order if the verifying velocity come after the change was made and before the expiration of the time limit.

Signals should be changed from one direction to another as necessity requires, and as indicated by the storm movement. It is not favorable to the Bureau to have easterly signals flying while a westerly storm is in progress, and this is one of the most important points I wish to make.

The Bureau should furnish the master with the latest information it has, and allow him the privilege of sailing his ships as best he may, using the information furnished by the Bureau as his best judgment dictates. A gale of 40 miles may be just what one master desires to assist him on his course, while another, going in the opposite direction, must lay to, awaiting better conditions. It is enough for the Bureau to accomplish to have placed within the reach of masters the opinions of our careful and experienced forecast officials. The masters will heed the warnings and sail their vessels so as to subserve their individual interests. It is our part to have the very best and latest information of storm movements, and see that it is promptly placed where the masters can have access to it; it is the part of the master to use this information so as to promote the interests of those he is serving.

The shifting of the wind during a storm period is a matter of vital importance to all mariners and should be especially looked to in making forecasts and ordering signals. When this point is well grounded, and the signals are changed promptly, I am of the opinion that the forecasts of to-day are well suited to the needs of the marine interests.

Advisory telegrams should replace signals where the winds are not of sufficient importance to warrant display; the methods of distribution are so systematic at the present time that no interest will be neglected by so doing. One decided improvement made in the past year is the displaying of signals only for important storms, and the use of the advisory message for warnings during the passage of minor storms or those which cause local disturbances only. This has been commented on very favorably by the mariners, and in consequence more attention is paid to the display of signals. The signals are now only displayed for important storms, and no important storm has passed over the Lake region during this period for which signals were not displayed in advance.

In speaking of local needs it should be taken into consideration that vessels sailing between Buffalo and Detroit have no means of obtaining information from the Bureau if they keep on their regular course. This is an argument for the discontinuance of the southeast signal on the south shore of the lake, as all harbors on the south

shore can be entered with safety during south or southeast winds, but not during the southwest, west, or northerly winds.

METHODS OF DISTRIBUTING FORECASTS AND STORM WARNINGS.

A forecast of the wind direction and force is sent to each wind signal display station on the lakes daily; the forecasts for all the lakes are sent to the regular stations; the forecasts for the upper Lakes issue from Chicago, and those for the lower Lakes (Erie and Ontario) from Washington.

These forecasts are posted in all the prominent places where shipping interests demand them. At the wind-signal display stations the masters of vessels lying in port are furnished with a copy of the daily forecasts and of all storm warnings.

The improvement in the distribution of the daily forecasts and storm warnings has been very marked during the past year; in the past three years more progress has been made in the matter of furnishing promptly the information of the Bureau to the masters than in the entire history of the service prior to 1895. When it is considered that, with one or two exceptions, the masters of steamers are in daily communication with the Bureau and are furnished with the latest information, it may be understood how far reaching and systematic is the present method of distribution of the daily forecasts and storm warnings. Let us, for illustration, consider a steamer going from Buffalo to Duluth. Before she leaves port, the master finds in his home office a copy of the forecasts for the next thirty-six hours and timely warnings of approaching storms. As he passes Detroit a weather map is placed in his hands by the excellent marine postal service at that point, and if a storm signal is flying, a copy of the warning message; should it be at night, in addition to the above, he is supplied with a copy of the p. m. report, giving the direction and force of wind at all lake stations. On his way up the St. Clair River it may be that an important storm warning has been issued; therefore, as he passes Port Huron, the marine reporter there hands him a copy of this warning. He passes up the lake, and the next day reaches the Sault; there he finds a weather map at the window of the office where he hands in his report to the officials of the canal, and very likely he meets our representative on the locks, who gives him the latest information and at the same time adjusts his barometer. After he leaves the Sault and until he reaches Duluth, a space of thirty-six to forty hours, he is without direct information from the Bureau, but he has the benefit of the display of signals at Whitefish Point, Deer Park, or Eagle Harbor, and when he again reaches Duluth finds the weather maps and storm warnings placed conveniently at his hand. Again, should he be sailing for Chicago, he is met by our displayman at the Straits of Mackinac and given a copy of the forecasts or storm warnings. At important points along his entire path are situated special wind-signal display stations, where storm signals are displayed, which indicate the direction and force of the wind, so that the safeguards of the Bureau are constantly within his reach. If he is at one of the display stations and desires later information than the displayman has, it is his privilege to telegraph for it at the expense of the Government either to Buffalo or Chicago. Even should he be in port where there is no Weather

Bureau station still he can telegraph for this information and it will not cost him a penny. The only requirement of the Bureau is that he shall give other masters in the harbor the benefit of the information which has been freely given him. Can anything be more complete than this for the protection of the mariner on the lakes? Is it possible to throw around him further safeguards than the Weather Bureau is now doing?

It is not necessary to go into details relative to the distribution of the forecasts and storm warnings at our regular stations, as it is well known that these are posted in all prominent places, and when storm warnings are issued or the conditions of weather are unfavorable the telephone and telegraph are used freely to spread the information broadcast. It is different with our displaymen. We employ men at the different points where our wind-signal stations are located to display the signals and to render the regular monthly reports during the season of navigation. These men post copies of the warnings in their offices and display the signals and answer such questions as may be asked by masters who visit their offices. But these men have other business to attend to; the amount of salary paid them for the display of signals is not large. However, I have found them to be ready and willing to assist so far as possible in improving the means of distributing the forecasts and storm warnings. The daily forecasts for the Lakes were first issued during last fall. At the opening of navigation in the spring copies of these forecasts were sent to all the wind-signal displaymen, with instructions to post them at two or three important points. This was done, yet it was found that the method of distributing these forecasts could be still further improved, and the logotype system was introduced, and now the displaymen stamp the message on a number of the forecast cards which are freely distributed to all points where the navigators congregate or where the marine interests demand these forecasts. This system has been gradually introduced at the stations so that eventually each station will furnish every master in port with a copy of the forecasts and storm warnings. The prime object is to place these forecasts within the reach of all masters on the Lakes so far as it lies within the power of the Chief of Bureau to do so.

Night signals.—At every station where business interests demand it night signals are displayed. Where possible, electric lights have been introduced this season. These are visible at a greater distance than the oil lamps and do not go out during the night as oil lamps do. With high winds the oil lamps knock against the staff and are jarred out, and so it sometimes happens that where we anticipate that our signals are burning and doing good service it is found that they have not been burning for a large portion of the night. In this connection it is proper to bring forward the subject of a permanent staff for the display of signals and the method of fixing the signal lanterns to the staff. An iron or steel tripod 50 feet high with a pole extending 30 feet above the top would make a substantial permanent staff and the lanterns can be fixed to these so as to make a very creditable display, and the signal lights would not be extinguished during high gales, when they are of the most importance.

Our telephone service.—The Bureau maintains two important telephone lines which have paid many times for their installation and maintenance. I refer to the lines between Alpena and Thunder

Bay and Middle Islands. These lines were established at a cost of \$20,000, and have been used extensively in saving vessels and property. In one instance the use of these lines was the means of saving a steamer and cargo, the value of which was placed at \$750,000, and many other instances could be given of the great value these lines have been to the marine interests of the Great Lakes. Alpena, lying so far in on Thunder Bay, is of very little service to vessels on the fairway of Lake Huron, but these vessels pass one or both of our display stations on Middle Island and Thunder Bay Island on their way up and down the Lake close enough to see the signals. We also maintain telephone service with the Life-Saving stations at Pointe Aux Barques, Lake Huron, and at Big Sable Point, Lake Michigan, signals being displayed at both points, and the telephone lines frequently used for the protection and saving of vessel property. These stations have been of such value to the marine interests that it is proper to state a telephone line between the mainland and South Manitou Island, Lake Michigan, would also be of great service to the Bureau and the mariners.

In concluding this somewhat lengthy paper I desire to call attention to one or two stations where reports would be of great service to the marine interests and enhance the value of the information given out by the Bureau. One is at Mackinaw, where the vessels pass to and fro in the mighty commerce of the lakes; one at Eagle Harbor, on the extreme point of Keweenaw; a third is at Whitefish Point. The first, because all vessels are reported from Mackinaw, and when we had a station there it was used as much by the marine interests as any on the lakes; second, Keweenaw Point juts out into Lake Superior and causes vessels to make a long detour to get around it, and we have no reports from that section of the lake. I am convinced that Marquette does not give the proper record from that portion of the lake. Several very serious disasters have occurred along this peninsula during the past few years. Third, at Whitefish Point vessels lay to in stormy or foggy weather, and being some 60 miles from the Sault as well as at the outlet proper of Lake Superior, the wind and weather conditions are very different from those reported from the Sault. This can be simply illustrated by considering the reports during the past season on Lake Huron from Alpena and Middle Island. At the latter point the wind is always stronger and often varies in direction from that reported at Alpena, some 15 miles away on the bay.

Finally, two important points should ever be kept in view; first, that the storm signal should only be displayed for important storms, advisory messages at other times; second, that an easterly signal should never be displayed during the prevalence of westerly gales, since the systematic methods of distribution of forecasts and storm warnings serve to assure the forecaster that each master has such information in his possession as promptly as possible.

Mr. MITCHELL. I would like to ask if Mr. Conger can give us the relative difference between the velocity of winds prevailing; that is, is a 25-mile wind from the east as dangerous as a 30-mile wind from the west.

Mr. CONGER. It is not a question of velocity of wind. So far as

velocity is concerned, there is no particular difference whether it is easterly or westerly. There is no particular point as regards the danger from wind velocity; it is simply a question of the location of the cities.

Mr. MITCHELL. I ask the question because there is some similarity between the conditions prevailing on the lakes and those on the south Atlantic coast. A wind velocity of 50 miles an hour from the southwest is not so much to be dreaded as a wind of 25 or 30 miles from the northeast. Of course southwest and west winds are off-shore, while the other is from the ocean.

(b) *Are the present warnings and displays by flag and lantern the best that can be devised for the Atlantic and Gulf coasts?*

JOHN W. SMITH, Boston, Mass., and ALEX. G. McADIE, New Orleans, La.

Mr. SMITH. In so far as has been indicated to me by expression from the public and from those especially interested in wind signals the present storm warnings are satisfactory. I am personally acquainted with the officials and numerous members of the Boston Pilot Association and the Marine Department of the Boston Chamber of Commerce, also with many masters, owners, and agents of vessels plying the waters of the Atlantic and Gulf coasts. In discussing the matter of wind signals with them on various occasions I have heard no expression of dissatisfaction with the lanterns and flags as now used. Neither have suggestions been offered for improving the signals. On the other hand, I have often heard the same parties commend the Bureau in the highest possible terms for timely warnings that have proved of the utmost value in saving life and property. While all this is true, and while the present system of wind-signal warnings might continue without complaint, unfavorable comment or adverse criticism, I am strongly of the opinion there is great opportunity for valuable improvement, particularly in the day or flag signals. I have for a long time entertained decided ideas as to how the flag signals might be improved, providing flags must be used. Some of these ideas have been expressed to the Chief of Bureau by me in letters and reports. I am of the opinion that the colors of the flags used should have no significance or meaning. My reason for this opinion is that the flags are most frequently displayed when the weather conditions are such that it is difficult, if not quite impossible, to discern or distinguish colors at any considerable distance. This statement is based on knowledge obtained from personal observation at various times and places. I think that perhaps this defect in our present system of warnings might be overcome, to a large extent by using flags of various forms, such as square and oblong; also pennants and streamers, and let the warnings be conveyed in this way, rather than through the colors. I believe that the shape of the flags and their positions in the display or hoist could often be distinguished when the colors would not be visible. This system of display would probably be more economical than the present one from the fact that the flags as now used must often be discarded on ac-

count of being discolored, while yet otherwise in good condition.

I am further of the opinion that a more decided improvement could be made by wholly discontinuing the use of flags and following somewhat the Canadian and other services by substituting cones, drums, and cubes. It is well known that flags can not be seen even under favorable weather conditions when flying to or from the observer, or in the line of vision, nor when hanging limp in calm weather. This defect could be overcome by the use of fixed symbols, something after the pattern I have mentioned or proposed, or perhaps by the use of semaphores. I am convinced that some such improvement in the flags or day signals would be a most valuable and highly appreciated addition to the system of storm warnings of the United States Weather Bureau. To discontinue the use of flags would doubtless entail quite an additional expense for signal equipments. This, however, would be in the beginning only, for after once being installed, I am confident the cost of maintenance of the new system would be much less than for flags. I, therefore, suggest and recommend that the matter of the change in the flags or their discontinuance and the adoption of a new system of signals receive careful attention and consideration.

In connection with the display of flags as now used, I favor and recommend a more frequent, in fact a very liberal use of the information signal. This oftentimes affords valuable information to the marine interests when it is impracticable to issue a definite warning. In fact, I am almost convinced that at times the information signal is all the warning that is required. In my opinion another weak point in our flag warnings, is that the orders for a change in flags indicating a shift or change in the wind direction are received too late, or after the wind has changed. The original display or hoist of flags should therefore, when possible, be such as to express the direction to which the wind will most likely shift. If this is impracticable, then the orders to change the signals should be issued in due season. I think the opportunity for improvement in this direction is great.

Another matter which I think might be considered is the display of the hurricane signal. I am not favorably disposed toward this as now used. As regards my own station, Boston; it is not popular, and I sometimes think the reputation, or credit, of the Bureau suffers at each display. This was certainly true for the first display of the hurricane signal. Perhaps the public expects too much; anyway, I believe it should be seldom used, and then when the doubt as to full verification is at the minimum. Successful displays are conspicuous evidence of the great worth of the Bureau.

As regards the signal lanterns, or night signals, it occurs to me there is little opportunity for improvement, where the standard or large electric lanterns are used. A point to be observed in the use of these lanterns is, to see that they are located far enough apart on the staff or support so that the lights do not blend at the most distant point at which they are likely to be observed or become useful. My lanterns are twelve feet apart. They were originally six, but it was ascertained by test that the distance should be increased to twelve feet. I believe these remarks cover the principal points wherein my knowledge and experience lead me to believe improvements can be made in the flags and lanterns as now used for the Atlantic and Gulf coasts.

Mr. McADIE. Every signal may be considered from at least three different standpoints. First, we have the signal as it is made; second, we have to deal with the transmission of the signal and the various ways in which communication can be maintained; third, we must consider the signal as it reaches the receiving station and the means there at hand to make the signal of real value. To illustrate: A message wigwagged from the shore to a man at sea in a boat without oars and entirely unable to move toward the shore is of doubtful value, unless the means of relief are at hand. Again, a light burning on the shore and obscured by fog is valueless. A signal transmitted by air waves as with sirens may be deflected and rendered misleading.

Under the first heading, that of the signal itself, we must consider legibility and ease of interpretation. Again, signals must be durable, economical, simple. On all these points, I think that the Weather Bureau signals in present use can not be very much improved upon. I do not agree with those who advocate the semaphore, cone, and ball, and other devices.

Under the second heading, "Methods of communication," I hold that the best signal is a telegraphic or telephonic message sent directly to the party most interested. I do not believe that our signals, especially storm signals, as displayed on the roof of some one high building in the heart of a great city are of much value to the community. It has been my experience that whenever such a signal is displayed the public makes reference to the small cards explaining such signals. The mere fact that such a card of explanation is necessary is to my mind proof that the system is too complex. Our hurricane signal is distinctive, so also is the information signal. Our other signals are confusing. The attempt to convey information of wind direction in a signal is not always successful. The value of wind directions varies with localities. What is a dangerous wind in one locality is a desirable wind in another. Moreover, the wind changes direction in some localities very suddenly. With our northers, winds have been known to change in the space of five minutes, and signals have been displayed for southeasterly wind in the face of howling northers. In all such cases the information signal should be displayed and the local office trusted to distribute all other information about the storm.

Finally, far too many signal orders are issued. Advisory messages are far preferable to signal messages unless the disturbance is so marked that the emergency signal is required. The points of improvement in our present methods are fewer signals, many advisory messages, and reliance upon the judgment and skill of the party receiving the signal or message.

Professor MOORE. In regard to Mr. Smith's suggestion that we use the information signal frequently, I will say that it occurred to me, when serving on the lakes, that we were using too many—the information signal, the cautionary signal, the storm or storm and hurricane. I think the information signal now is quite well superseded by the frequent information message, a copy of which is, at every port, placed in the hands of the master of every vessel, rendering it somewhat unnecessary to raise the information signal, which simply says that

the observer has information useful to him. We send the message direct to the master and obviate the necessity of putting up too many signals.

Now, as to the change in wind direction, I think both Mr. Conger and Mr. Smith have suggested that the wind direction on the signal display should be changed before the wind shifts. We are assuming, of course, that the official signal went up in advance of the storm, as it does in nearly every case. Now nearly every vessel master knows that if the indication is for a southeast wind, it may veer to the south or southwest, but if the signal is raised for a northeast wind, he is somewhat in doubt, because it may back to the north or northwest. But the point I want to make is that such officials as Mr. Smith and Mr. Conger have authority to change these signals and telegraph their action to Washington. You also have not only discretion but you are encouraged to telegraph the Central Office your opinion on a signal at any time.

Mr. CHAFFEE. I think the direction signal is very important to the Atlantic coast interests. At Wilmington, when I had charge of that station there, and at the mouth of Cape Fear River, frequently vessels would come out of the river from Wilmington, bound across the ocean; when they left Wilmington, 40 miles up the river, there were probably no signals at all displayed, but during the time it took them to go down the river and pass out, storm signals would be ordered at Wilmington and repeated at the mouth of the river. Now, if that signal indicated an offshore wind, the vessel should keep on, but not having the direction signal they would have to drop anchor, row 8 or 10 miles ashore, get information that the wind was fair, up sails, and get out to sea. The direction signal, I know, in several cases has saved just that delay.

Mr. SIMS. I desire to call attention to the fact that it is possible to convey information of extreme importance along the Atlantic coast, and also in the Gulf section, by means of a simple mechanical contrivance that can be placed within a distance of 3 to 5 miles of a settlement, which would give ample warning to the settlers of the section that a tornado was approaching or a wind velocity of from 40 to 60 or 80 miles an hour, or any velocity you deem it important for them to have knowledge of. You simply make a loop in the telegraph line at a point from 5 to 6 miles from the settlement, and upon every pole of the loop place a pointer properly weighted, and also a small board guyed with a wire capable of standing a strain of 40 miles per hour, or more; when the wind attains a velocity of 41 or 42 miles that wire will be broken, the circuit completed, and an alarm sounded in the settlement that will give workers in the field

from five to ten minutes to hie to places of safety. Also, with slight alterations, the contrivance alluded to would serve a good purpose in the vicinity of reservoirs and places where water is stored.

Professor HAZEN. We are somewhat at a disadvantage here in that each one is looking at the question from a different standpoint. I have noticed that of those who have spoken one has advocated one thing, and another just the opposite. Now the forecaster at Washington is in a quandary to know how he is to satisfy all interests, and we must be very careful to bear in mind that the larger steamers are not the only vessels we are warning. They, especially sea-going steamers, care very little for signals, but on the lakes we have coal barges which can not stand a wind of perhaps 30 miles without being sunk, and on the sea coast we have vessels which demand the signal larger vessels do not care for. Now, it seems to me that while the message is all right for the larger interests, it does not reach the smaller interests, to which our signal is more important than to the larger vessels.

In regard to the use of the drum and cone, it is a surprising fact that the Belgians and English, and several other nationalities are using, and have been using these signals for twenty years. Now, why do they do it? It seems to me there must be a great deal of merit in that signal. I have thought, when investigation was made some years ago at Washington into these drum and cone signals, that there was too great belief that the flag signal was all right, and not enough thought given to the cone signal. I think possibly we can advance in that direction. I would like to see experimentation continued along this line, to see if the foreigners are right in this matter and we wrong. As to the different shape of the flags, when a flag is tight down to the mast you can tell nothing about the shape. In such cases I think the color very important, and it seems to me that the signals which have been changed from time to time are nevertheless as near the best as can be had, so far as our experiments up to the present time indicate.

Mr. MITCHELL. I think there is one point of very material importance in discussing signal displays. I refer, of course, to my own section of the country, Florida. As I said a moment ago, when I approached Mr. Conger on the question, a velocity of 25 miles from the west will not delay a vessel sailing from Jacksonville to sea, because there are no breakers on, and she proceeds without hesitation, while a wind of 25 miles from the northeast or east does affect her proceeding very materially; and I have had masters of vessels come up to the office and ask particularly regarding the expected change of wind, because they desired to avail themselves of it; and

although I had orders to do so, I have felt a delicacy at times, in hoisting a northwest wind signal; that vessel master desired that very wind. Of course it is impossible for the Central Office to appreciate the situation at every station, and in such cases it is the duty of the official in charge to apprise the Central Office of the facts in the case.

Regarding information signals and other signals displayed along the south Atlantic, experience justifies me in finding no fault; we have had no complaint from any source. The people have learned to respect them down that way, and when we hoisted the information signal on the first of October, nearly thirty-six hours in advance of the recent hurricane that passed up the coast, and the hurricane arrived on time, of course it emphasized the fact that we knew what we were talking about, and the people gave us due credit.

Professor MOORE. The discussion that has taken place about the direction signal seems to me to raise the point as to whether we should hoist the signal for a wind that is offshore, and therefore not dangerous. I always consider that when we give the direction signal mariners know the velocity we expect to get for that signal, and they may put up sail or get up steam and go out in the face of the signal if it says offshore. It does not necessarily mean danger, the way I interpret it. It means an offshore wind, and if you are going to a distant port and don't want to come back, go ahead; but if you have a small vessel and want to return in a few hours, then don't go. The mariner will make his own interpretation if you give him the facts. By the information message which we have sent so frequently during the past several years we keep vessel masters informed every few hours of the movement of the storm. The storm center has moved so many miles since last report; it is increasing or it is decreasing; the storm is dying and will not come to you; or, it is increasing and will come to you with great fury; or, a storm is coming, don't go out. Such messages keep the mariner fully in touch with the storm's progress, and he is able to make his own deductions. If we give him all the facts we have in our possession, he will make the best use of them and apply them to his own case.

As to the flag signal, that has always been a question. We have not yet been able to find anything better than the flag. Professor Hazen says that as the Belgians have displayed form signals for so many years, it must be evident that they have value. I may say, however, that we have displayed flag signals for twenty-six years, so we may be assured they are fairly successful. In fact, I don't think we have much to learn in meteorology from foreigners. I heard the presiding officer of the geographic section of the British Association for the Advancement of Science, two years ago at Toronto, say that

the meteorological service of the United States Government was the admiration of every Briton and every scientist of the old world.

Professor ABBE. The cone and drum signals have the great advantage that they can be seen from all directions, but they are pretty heavy things to handle and are not raised up very high. Our flags go to the top of very tall masts and can be seen a great way off.

The Convention, at 12 (noon), thereupon adjourned.

OCTOBER 13, 1898: AFTERNOON SESSION.

(c) Possibility of giving warnings of northers, cold waves, and heavy snows to stock-raising interests forty-eight hours in advance.

F. H. BRANDENBURG, Denver, Colo., and E. J. GLASS, Helena, Mont.

Mr. BRANDENBURG. As is well known, cold waves, northers, and heavy snows are especially severe on the Great Plains. In the past few years no severe storms have occurred unannounced, so far as I know, though occasionally the warnings were in point of time too late to reach the interests scattered along the eastern slope of the mountains from the British Northwest Territory to Texas. This arid and semi-arid region being especially adapted to grazing, millions of dollars are to-day invested in cattle and sheep. No interests are more affected by winter storms than those of the live stock. Next to these storms, and not much less serious, are the cold rains and wet snows of spring. Coming as they do at the lambing season, and at the time when stock cattle are poorest in flesh, considerable losses always occur. The cold rains are even worse than snow, for they penetrate to the skin.

A great change in this business has taken place since early in the eighties. In those days large herds were driven from Texas and turned loose on the ranges of Colorado, Wyoming, and Montana during the summer; if gathered at all the following spring these were found by the round-up scattered hundreds of miles to the southward, where they had drifted with the wind. At the present time large open ranges and vast herds are for the most part things of the past, except in Montana. The herds are generally small, and in the hands of ranchmen, and, though obtaining the bulk of their sustenance on the adjacent open range, can be gathered at short notice and cared for during storms. This change in the manner of conducting the business makes it possible for the industry to profit by the storm warnings of the Bureau, especially if it be feasible to make these forty-eight hours in advance.

The difficulties attending the making of predictions so long in advance are considerable, owing to the influence exerted by the Continental Divide and the nearness of the interests to be protected to the locality where these storms originate. As every cold wave that sweeps over the Great Plains is the joint product of a strong anti-cyclone over the north Pacific or the British Northwest Territory, and of a depression of more or less intensity in the south, 48-hour warnings must in the majority of cases be based not on a high area, but on the position of the low area and the shape or type of the isobars.

In many instances the low area in the south is ill-defined, or that region may be occupied by an area of moderately high pressure. Increased warmth and cloudiness on the eastern Rocky Mountain slope with southerly winds in central Texas often give valuable indications of the formation of a disturbance. Then, again, these signs may be lacking east of the mountains, but a low may apparently occupy Arizona. The latter is often misleading, but when the isobars in the distant south run from east to west, with little curvature, and the arrows at Arizona and southern California stations point southward, it is safe to conclude that within forty-eight hours a low will make its appearance over west Texas or New Mexico. Meanwhile, if a high area is not already present in the northwest one is likely to form; its intensity, however, is difficult to conjecture. If we wait for the high area to develop, its growth and movement are so rapid that scarcely twenty-four hours elapse before the front of the storm is well on its journey southeastward, its progress being facilitated by the down grade.

The region west of the Continental Divide rarely suffers from the cold waves which advance from Montana, but the high pressure areas of the north Pacific, especially when they move well up over the northern plateau before moving southeastward, often cause rapid and marked falls of temperature in that region, even though the high be attended by temperatures above freezing in Washington and Oregon. Often the progress of these cold waves from the north Pacific is so rapid that a 24-hour warning is all that can be given, for the mountains do not impede their progress as they do that of the low areas. These highs bring snow to both slopes, and when the low is in the form of a trough reaching from Arizona to the Great Lakes the fall of snow is heavy and a sharp fall of temperature follows, principally as the result of unobstructed radiation. The movement of the high being southeastward the trough is cut in two, the northern half moves northward and the southern half becomes the principal storm. If, in winter, predictions of a cold wave, or if, in the fall or spring, predictions of a heavy snow, be delayed until the high forms, then a long notice can not be given to the ranchers. But if the forecast is based on the trough, which first appears as a low over Oregon, the next day as a trough over the Plateau region, the northern end of which usually moves the faster, then it can be made with great accuracy on the first appearance of rising pressure over California or to the northward. Forecasts of severe storms, with the above distribution of pressure, can be made with greater accuracy than when the high is north of Montana.

Existing instructions require that certain changes in the barometer during the two hours preceding the observation be telegraphed by a special cipher word from selected stations. As the stations in the west, as a rule are far apart, and moreover as so large a per cent of the storms cross or originate in the Rocky Mountain region, it is thought that good will result if all the stations west of the ninety-fifth or one-hundredth meridian be required to add the word representing the change. By means of the additional stations that are to be established west of the Continental Divide it may not be so hard in the future to determine where a given low will cross the main range, whether in Montana or Wyoming, or through the Royal Gorge of the Arkansas, or the low mountains of New Mexico.

It may not be out of place to refer to what, to me, seems to be the principal cause of such failures as occur in connection with forecasts of cold waves for the middle eastern slope, based on high areas over Alberta. These failures occur principally when a low overlies the northern Plateau and British Columbia, for then the latter may be expected to exert the controlling influence on the weather of the middle Rocky Mountain region, and we have the anomaly of winds blowing against steep gradients. When, however, a high occupies the upper part of the northern Plateau precipitation and cold over-spread the entire State.

In view of the value of barometric readings from British Columbia, it is to be regretted that the reports from Kamloops are so uncertain both as to their receipt and accuracy. Turning now to the south I venture to express the belief that reports from Chihuahua, Mexico, would be of great value in connection with 48-hour predictions of cold waves in the United States along the eastern slope of the mountains, in connection with northers in Texas as well as with the heavy precipitation of the central valley.

Professor MOORE. I am sorry we can not give more time to the discussion that might be engendered by Mr. Brandenburg's paper. He is one of several forecast officials that were recently commended as a result of the verification of the work of the local officials in comparison with the state officials. His differing forecasts showed a very high percentage; showed that he had differed with such judgment as to have improved the forecasts. I commend the study of his paper to every local forecaster in the Rocky Mountain region. All these papers will be issued in a pamphlet soon after this Convention adjourns, and to the forecasters of the Plateau region I especially commend the study of Mr. Brandenburg's paper; he can be considered an expert in forecasting in the Rocky Mountain region.

Mr. GLASS. In writing on this subject we have first to become acquainted with the three principal points on the subject, namely, cold waves, northers, and heavy snowstorms. A cold wave is a fall in temperature of 20° or more to a minimum of 32° or less in any twenty-four hours, without regard to the wind velocity or direction, while a norther is a fall in temperature to below freezing point with the wind 25 miles an hour or more from a northerly direction, accompanied by heavy snow.

Meteorology is an inductive science. It is a science in which we gather the facts by observation and arrive at the laws of the weather by induction therefrom. We are peculiarly situated for gathering these facts; we are located at the bottom of an ocean of air, composed of invisible gases, which on pressure becomes warmer or upon being rarified become colder. This wonderful mixture of gases, although very light and invisible, is weighed by the barometer, its movement is indicated by the anemoscope, and its velocity is measured by the anemometer. The thermometer also fills a most important part in our work of gathering facts relating to the air. One essential property of the air is its power of holding vapor of water; another is its ability

to expand when heated; another is the increased capacity of heated air for carrying aqueous vapor; finally its property of cooling by expansion, thereby causing condensation of vapor and precipitation of moisture in the form of rain or snow.

The sun's heat is the prime power that underlies our entire meteorological science. By the sun's heat the air in a certain locality becomes heated, expands, and rises, while the surrounding surface air moves to replace it. All bodies moving on the earth in any direction in the Northern Hemisphere are swerved to the right by the earth's rotation. The movement of the air in the above case conforms with the law just cited, and a gyratory motion is commenced; the nucleus of a storm is formed and it starts on its eastward journey. These areas of low pressure are followed by high pressure areas, the average rate of travel being about 37 miles per hour during January and February, but gradually decreasing until July, when an average of 22 miles an hour is recorded.

It is generally understood that nearly all cold waves originate to the north of the United States and travel in a southerly or easterly direction, and pass along the east side of the Rocky Mountains accompanying areas of high and low barometer. These are the barometric waves that we must consider in the discussion of our subject. When the center of a storm has passed a given place, the winds veer suddenly to the west or northwest. When the cold air that rushes in causes the temperature to drop 20° or more it is called a cold wave. It is commonly said in the description of these storms that the cold winds come from the north where the storm originated, but on the contrary, by the action of the high and low areas, the cold may be generated and brought down from above in the near vicinity of the storm itself.

The conditions most favorable for cold waves in Montana are the presence of an area of low barometer in southern Idaho or Utah, and another low area coming down from the northwest followed by a high, entering Montana near Havre. This barometric depression is accompanied by southerly winds, and by abnormal warming up of the atmosphere in its southeast quadrant. When the center of the storm is past, the winds veer to the west with increasing velocity, and the temperature falls 25° to 40° in a very few minutes. This class of cold waves is always accompanied by heavy snows and high winds, thus combining in one storm the three principal points in our subject. This is the kind that is most dangerous to the cattle and sheep interests, because the warm weather preceding the storm induces the herder to drive his flocks away from the place of shelter only to be caught by the cold waves and northerers. This class of cold waves travels much faster than those accompanying the high areas, and many incredible stories could be told in the history of Montana cattle and sheep industries of the destruction by these storms or the narrow escapes therefrom.

The large cattle companies of the State can not use forecasts to advantage, as it is impossible to keep any knowledge of the number or condition of the stock on their extensive ranges, except at the spring and autumn round up. The spring round up is for the purpose of branding the increase, and the fall gathering is for shipping purposes. We have interviewed many of the large owners of cattle who reside at Helena, and while they are much interested in the work

of the Weather Bureau they regret to acknowledge that they can not receive the benefits of the warnings. The larger owners of cattle generally have summer and winter ranges for their stock, and at the round up the cattle are changed from one to the other according to the season. The winter range is located, where the most shelter can be had for their stock during the prevalence of the cold waves. Accurate long-range forecasting by seasons would greatly benefit the cattle industry. But while the large owners can not utilize the warning, there are many farmers and ranchmen who possess small herds of cattle that aggregate thousands in all, who reap the benefits of the forecasts, and to whom a warning of twelve to twenty-four hours in advance is very beneficial.

The sheep industry of Montana is quite large and is greatly benefited by warnings. The facilities for distributing cold wave forecasts to the sheep men are very good, and they can be protected by these warnings. Sheep are always accompanied by a herder, and in case of a warning he will either house his herd or drive them northwest of their shelter so that when the storm arrives the herd will drift home with the storm.

The cold wave that comes with a high barometer without wind is not so disastrous to stock. The cold air settles and stratifies along the ground, there being no clouds, the greater portion of the cold is derived from radiation. This class of cold waves, as a general rule, does not worry the stockmen very much, if the ranges are free from snow. These travel very slowly and cause a long protracted cold period. On several occasions, while the thermometer registered -25° to -30° at Helena, whose elevation is 4,108 feet, the temperature of a place less than 8 miles away, at an elevation of 7,000 feet, was being registered as above the freezing point, and snow was rapidly thawing, thus showing a thin stratum of cold air at Helena.

The possibility of making warnings forty-eight hours in advance of cold waves, northerly, and heavy snows is not very encouraging for localities so far north as Montana. Our knowledge is so limited as to the probable direction and motion, and their rate of travel is so rapid that it is very difficult to determine whether their course will be east over Manitoba, or southerly through Montana, the Dakotas, and the upper Mississippi Valley.

It is thought that the important facts to be gathered from aerial observations obtained by kite flying will reveal new laws as to the currents of air in the upper atmosphere, and will enable the forecaster to be warned in advance of the approaching surface conditions, thus enabling him to predict, with certainty, forty-eight hours in advance. But with our present limited knowledge it is believed to be impracticable to make 48-hour forecasts west of the Mississippi River, unless stations be established over the Northwest Territory and Alaska.

(d) Warnings of washouts, floods, cold waves, and heavy snowfalls for the benefit of transportation companies.

J. WARREN SMITH, Columbus, Ohio, and T. S. OUTRAM, Minneapolis, Minn.

MR. J. WARREN SMITH. I have just one word to say to forecast officials relative to flood warnings, namely, that they take into account not only the depth of snow over the drainage area but whether that

snow is in stable or unstable equilibrium; whether it is full of water, so that a small rain will cause a flood, or whether it is mostly in the form of ice. I think in addition to reporting the depth of snow reporters should give the water equivalent of the snow and whether the ground is frozen or not. I believe that it is important that transportation companies, especially during the spring season, should be informed in advance of the condition of the snow, of the condition of the soil, whether it is full of water or whether it is full of frost, whether the roads are liable to be washed out easily, and that we should supplement our flood warnings by keeping transportation companies informed in advance of these conditions. In arranging for these flood warnings for transportation companies, I also believe that we are not particular enough to see that the right man gets them. We should make a personal visit to the roadmaster or chief official of each electric or steam railroad, and be sure the warning reaches not merely some official but the right man at the right season.

Mr. OUTRAM. In the discussion of the subject, "Warnings of washouts, floods, cold waves, and heavy snowfalls for the benefit of transportation companies," which has been introduced by the previous speaker, the interest naturally attaches to the following features, namely, the present value of these warnings to this large class of our industrial interests, their dissemination, and the possibility of improving both the forecasts or warnings, and the manner of placing them where they are needed.

Floods.—In its flood service our Bureau has been remarkably successful, in fact its system of flood warnings becomes its most valuable feature during those seasons when great floods create such enormous loss of life and injury to property of all kinds exposed to their fury. Transportation companies, on both land and water, value these warnings most highly, since they are so timely that by them they are enabled to remove valuable freight to places where the rising waters can not cause injury. The masters of vessels have time to place their craft in advantageous positions, where the violence of the flood is less, or where the ice, which so often accompanies the flood, can not wreck them. The railroad companies along those parts of their lines subject to high water in flood years have opportunity to strengthen weak places in the road bed, to see as far as possible that there is a free discharge of water through bridges, culverts, etc., and so to arrange their forces of workmen that they may be ready at every point to act when the danger arrives.

Washouts.—I consider washouts as incidental to floods, for where there is not an excess of water from some source there can not be washouts, and warnings of floods certainly convey to railroad men at least the possibility of washouts. Our most sanguine forecasters can hardly hope, at present, to be able to issue warnings of those small and local but sometimes disastrous floods and their attendant washouts, resulting from the so-called cloud-bursts. To do this would require a skill in forecasting that as yet we can scarcely hope for.

Distribution.—The subject of the distribution of flood warnings to boatmen and others who are not in frequent communication with our stations, or substations, and the improvement of the flood service by increasing the number of precipitation stations and river gauges, or

in any other way, I must leave to those whose work in this part of the service has made them more competent to discuss the subject than I am. The special difficulty in conveying information to railroad officials at such times is a break in the telegraph wires, but the characteristic energy of the railroad man will overcome many difficulties when he needs to obtain something which he prizes as highly as he does these warnings.

Cold waves.—Cold waves are of frequent occurrence in our northern part of the country, and they are not infrequent in other parts. They are such unwelcome visitors to our railroad interests, that when the subject of Weather Bureau is mentioned to him, the railroad official's first thought seems to be of a cold wave. During the past four years or more a law firm in Minneapolis has been especially looking up the cases of damage by cold to fruit shipments while in the care of the railroads, and has collected large sums of money from the companies so frequently, that the fear of losing perishable freight by exposure to cold seems to be instilled into every employee's mind so deeply that cold-wave warnings must be his hourly dread during their whole season. No one can compute the enormous value of the shipments during the cold-wave season of such perishable freight as tropical fruits, apples, potatoes, eggs, groceries, drugs, and many other commodities, seeking a market in all directions over the immense territory that is liable to injurious temperatures. As the railroad companies are responsible for the good condition of all freight delivered, it is easy to understand the benefit of a system which warns them of that which causes their heaviest losses, and it is no exaggeration to say that the pecuniary advantage of the cold-wave warnings to these transportation companies is beyond the possibility of estimate.

To enumerate instances when, on receipt of cold-wave warnings, whole trains of fruit have been run into roundhouses for shelter, when shipments have been held back or their character changed, when apples or potatoes have been hurried east, and held back from the west, or when the freight cars have been warmed by lamps or stoves placed within them for protection against cold, would only take up time and add nothing but detail. The cold-wave warnings, together with the regular weather forecasts, are used by many train dispatchers in deciding whether their trains shall be lightly or heavily loaded, and whether they shall make long or short runs between switching places. It is a daily occurrence during winter for freight agents to ask me by telephone for the probable night temperature, and the information is used in deciding as to the disposition of freight in their care over night. It must not be gathered from the preceding that the railroad officials think the Bureau has attained absolute certainty in predicting injurious temperatures; they regard them only as warnings and as reminders that their freight may be injured if taken too far from shelter. They know that it would not be profitable for them to be too cautious and run no chances at all of injury by cold, as they would then have large damages to pay on account of delay.

Blizzard and snow.—Warnings of heavy snows, or blizzards, as they are commonly called, hold an important place in the beneficial work of the Bureau, but as the warnings are comparatively infrequent they do not attract so much attention as the more frequent cold-wave warnings. A real blizzard is much more severe on trans-

portation than a cold wave, and consequently it is far more dreaded, for it blocks the roads completely and prevents all escape from the cold, which generally accompanies or immediately follows the heavy snow. It is during these blizzards that we hear of the intense suffering experienced by train crews and live stock on the stock trains, and sometimes of the loss of many carloads of valuable freight by freezing. Unfortunately, the snow warnings are not always early enough. When there is a severe blizzard, ample warning and the best preparation that can be invented by man could not keep the tracks open and prevent loss, but timely warnings are useful, as showing the need of precautions for getting perishable freight into safe places, and leaving the tracks open for only those trains best equipped with appliances for fighting the snowdrift.

When the sky over the whole country is beautifully clear, and a high pressure area overlies the whole Northwest, it seems impossible to bring oneself to believe that a heavy snowstorm is impending, and it may be due to this feeling that many snow predictions come too late. Heavy snows seem to snuggle, if I may use the expression, right up under the rear edge of the most pronounced highs, and they move eastward with great rapidity. The distribution of warnings of all kinds to railroad officials is very easy, and I do not see that it can be improved. The information is so valuable to them that they immediately distribute it themselves to all points on their lines where it will be of use. Our Minneapolis officials sometimes get warnings from their Chicago offices before the information can be telephoned to them from my office.

Forecasts.—The remaining point is by far the most important, and that is the improvement of the forecasts themselves. A few years ago the proficiency we have now attained was not dreamed of. A few years hence the advance we have made may be laughed at. Our mistakes are simply the necessary result of our yet imperfect knowledge. Nevertheless continued progress is evident, and with constant application, and the thorough investigation of new fields in the physics of the atmosphere, it must eventually come about that some laws will be discovered by which we can predict the degree of cold in a cold wave with considerable accuracy, and foretell the region affected by it, and also predict the intensity and location of snowstorms. If the imperfect warnings now issued are valuable beyond computation, who dare say as to the value of the warnings of future years, when it is reasonably certain that they will be verified almost to the very letter?

(e) *What classes are most benefited by the forecasts? Are they just what are needed? Are they properly disseminated and utilized?*

J. R. SAGE, Des Moines, Iowa, and H. C. BATE, Nashville, Tenn.

Mr. SAGE. What classes are most benefited by the forecasts? This question has been asked me repeatedly, and I should say that all civilized mankind within the realm affected by the Weather Bureau is about equally benefited. I have had to meet that question at farmers' institutes. "What benefit is it to the farmers?" they ask. Is it not largely for the benefit of commerce? Yes, directly. It is, you might say, almost two-thirds or three-fourths for the benefit of commercial interests directly—transportation lines and the commerce of

the ocean, the lakes, the rivers, and transportation overland. The saving of wheat and other grain on the Great Lakes, the saving of perishable products in transit overland on the railroads—all this directly affects the commercial interests. "Where does that benefit the farmer?" the farmer asks. Would we not be benefited by having five or ten millions of bushels of wheat sunk up in Lake Superior, or elsewhere, and thus lessen the overproduction? But the farmer would not be benefited; he would be damaged. Every hazard there is on the line of transportation between the producer and the consumer is at the cost, largely, of the producer. Every element of hazard in transit of the products of the farm is at the cost of the producer; ultimately the producer and the consumer pay it.

So you can see at a glance what classes are benefited by the forecasts. If you are talking to a farmer, talk directly of his interests, and the wideawake farmer will appreciate the point you make. I could bring you a number of illustrations to sustain my proposition, but I leave you to work out the details along that line. You will find it an interesting study and a profitable thing for the Bureau and the farmer as well.

Mr. BATE. I consider myself fortunate and happy in having to follow my honorable colleague on this question, because he has outlined in such beautiful and eloquent language the facts and propositions set forth in the topic. In hearing these interesting discussions and in looking over the varied interests involved, I am reminded very much of a conversation I once heard of between a very large, muscular man, who went into the subject with a kind of sledge-hammer blow and got there in a few words, and a little, fidgety, nervous man who beat around and finally arrived at the same conclusion by a road ten times as long. The big man said "Do you know, Mr. Dawkins, I think that what is one man's food is another man's poison?" The other said: "Well, I won't go so far as to say that, but I do think I can safely say I am of the opinion that what would be beneficial to one man and pleasant to him, would be unpleasant, and I might say deleterious, or I might go so far as to say absolutely fatal to another."

Now, for example, in the great raisin districts of the San Joaquin Valley of California, a warning of rain carries with it the fear of loss of many thousands of dollars, and to protect the fruit exposed in the vineyards during the process of drying by sheltering it entails a great expense, even if the warning is not verified, while in some sections, either contiguous, or at least not very remote, the verification of such a forecast results in untold benefits; in short, some pray for dry weather, others for rain.

There is scarcely a community in this vast domain of ours that is not directly or indirectly benefited by the daily forecasts or special warnings. In the early summer when the fields show the ripening grain and hay, when to reap or mow becomes a vital question; in the early fall, when the season for frost approaches, forecasts and warnings are noted eagerly by the growers of cotton, tobacco, and other products liable to injury and shortage. In the latter periods, when the time for the seeding of winter grains is at hand, the forecasts of timely showers are hailed with joy; and in the winter, when perishable products are to be interchanged from north to south, and *vice versa*, shippers consult closely the forecasts from the Bureau that

give them time to protect their produce; breeders of fine stock take advantage of the warnings to shelter their valuable droves, herds, and flocks from the effects of severe cold waves; florists and market gardeners prepare for the coming changes; river men watch with interest the forecasts of the rise and fall of the rivers and the warnings of floods, and those who "go down to the sea in ships" are guided in their movements by the signals which give warning of the approach of dangerous winds. I might continue the list, *ad infinitum*, to illustrate how thoroughly the information permeates and affects all classes and conditions of our citizens and their varied industries, but this would far transcend the limits of my allotted space.

As to the second proposition; human wisdom has not yet reached the plane of perfection, therefore the methods of the Weather Bureau are not infallible. It is said, and truthfully, that the science of meteorology is yet in its infancy. As long as we must explore only the bottom of our great atmospheric ocean, and until we can penetrate beyond this lower stratum, we must act according to the lights before us, and give to the people the benefit of present attainments in the deductions from atmospheric conditions as they appear from day to day; as it is, I think the excellence of the information, as is now presented, that is, the rate of verification, can not fail to satisfy a very large percentage of those who would profit by the forecasts; indeed, with existing defects they have become virtually a necessity, and as the public becomes more and more educated to the importance of the Bureau as the protective factor in the economy of our Government, the realization of its excellence, even in its present embryonic state, becomes more and more patent.

Until the systems of signals and other means of reaching the great mass of our people, the agricultural classes, have reached a higher plane toward perfection, we must content ourselves with these methods. Where our railway schedules and daily cross-country mails render it possible to place the daily map or the postal card forecast within the reach of a community it is done through the cooperation of public spirited men, who generously give a portion of their time each day, in supplementing the work of the forecast centers by scattering broadcast from their respective display centers the information emanating from the Central Office, and it is gratifying to know that the efforts made in this direction, and the constantly increasing dissemination of the forecasts, are being more and more perfected and appreciated. As the demands increase I have no doubt that the wisdom of our National legislators will prepare for even a more thorough dissemination of the information than our present limited resources will permit. As it is we all must feel a pride in the successful efforts of our honored Secretary of Agriculture, seconded by our worthy and progressive Chief, in advancing into our newly-acquired territory, and that of our friendly neighbors in the Tropics, and almost simultaneously with the flinging to the breeze of "Old Glory," hoisting the storm signal for the benefit and protection of the commerce of the nations.

(f) *Long-range forecasts: Can they be made with sufficient precision to be of general utility?*

Prof. H. A. HAZEN, Washington, D. C., PATRICK CONNOR, Kansas City, Mo., and B. S. PAGUE, Portland, Oreg.

Professor HAZEN. I will leave the serious side of this question to those who are to follow me, and will proceed in a lighter vein. Our newspapers are very ready to publish so-called forecasts of the weather a month or even a year in advance, and it is remarkable how much confidence is placed in such pure guesses by respectable people. The explanation, in part, at least, lies in P. T. Barnum's *bon mot* "the American people love to be humbugged." It is a well-known fact that we are very prone to remember coincidences in such cases, but very likely to forget failures. It will be of interest to inquire as to the principles on which such guesses are prepared, for, strange as it may seem, all these men have a supposed cause for all the effects they describe as about to occur in a month, year, or one hundred years just as well. All these men adopt cosmical or extraterrestrial forces as acting upon our weather. It is impossible to see how such cosmic force can act to produce a storm unless it act uniformly over a whole hemisphere. To say that a storm will occur on any day and then claim a verification because a storm occurred at one point is of no account really, for two or three storms are active somewhere in the Northern Hemisphere every day.

The moon has been the commonest of all extraterrestrial forces to which weather changes have been ascribed. If the moon can raise a tide of 60 feet in the Bay of Fundy it must produce tremendous tides in the air, and why should not these, in turn, give us our weather changes. The fact that this enormous tide is due to the configuration of the coast, and that the greatest tide in mid-ocean is less than a foot, is lost sight of. One theory asserts that the moon draws the air into a lenticular form, and this air lens concentrates the sun's heat so as to give us severe storms. The moon is known to be inert and dead. Its surface exposed to the sun may have a temperature of boiling water, while at new moon the dark face may have a temperature of 200° below zero, but neither of these conditions affects our atmosphere, and in fact, the most refined methods of observation have shown scarcely the difference of $\frac{1}{1000}$ of a degree as the range of influence from the bright and dark moon.

The planets, however, have yielded the most powerful of all theories for weather changes. It seems most extraordinary that any person, after considering the immensity and power of the sun, could for a moment think that one of his tiny attendants, itself entirely dependant upon the sun for its light and heat, can overpower the effect of the sun, and produce storms of its own in localities. Here is one of these theories:

The planets, comets, etc., go through a reversed change of motion, volume, distance, and density at perihelion and aphelion each orbital revolution, which are effected through reciprocating electric currents or lines that exist and undulate between the planetary bodies. These changes are the cause of our most violent storms and earth disturbances. The perihelion and aphelion passages of the planets, the oppositions and opposite positions of the superior planets, the inferior and superior conjunctions of the inferior planets, and the eclipses of the sun and moon constitute the first grade of meteoric disturbances.

Others claim that the planet has its greatest effect when it is

farthest from the line between earth and sun, or at quadrature instead of in conjunction. These opposite theories produce the novel result that the fair days of one are exactly the storm days of the other and *vice versa*. Notwithstanding this plain contradiction, however, each one claims a perfect verification for his own guess.

Of course any rigid system of forecasting for a well-defined locality and a verification by a strictly impartial rule would settle the question of the value of these guesses at once, and it would seem as though these planetarians would eagerly accept such methods. On the contrary they absolutely refuse to allow any one to verify a forecast. In one instance one of these men submitted a forecast for each day of a whole month, and also a curve showing the resulting temperature, which he claimed gave a complete verification. After a while the same forecasts were sent back to him and with his curve exactly reversed; that is, the cold points in the first curve were sent back as the warm points in the second and *vice versa*. Notwithstanding this exact reversal in the result, he claimed a perfect verification of the guess.

A thorough acquaintance with the methods of these planetarians will convince any one of the uselessness of such guesses. We must look to the sun alone for all our weather changes. It is very certain that, with a very few exceptions, no definite forecasts can be made for a period greater than forty-eight or, at the most, seventy-two hours; also, that none of our weather changes are due to lunar or planetary influence. Whether we may ever be able to make a forecast three months or even a month in advance is an interesting question. If the state of the ice in northern latitudes affects our weather, then by obtaining information from these far-north points we may hope to give a general idea of the coming season, but even then it will plainly be impossible to make a definite forecast for an individual day.

MR. CONNOR. I presume that since the fulfillment of the long-range forecast of heavy rain which floated Noah's ark, and perhaps a thousand years before, there have been a few people, at least, who have considered it within the bounds of knowledge or so-called science to make useful long-range forecasts of the weather, but unfortunately the success and skill of those wise wits of weather, those soothsayers of simoons, those human horoscopes of heaven can be measured only by the diversity of human eccentricity, superstition, and public credulity. There are those to-day who think that the laws governing long-range weather forecasting are hidden in impenetrable gloom, while there are others to whom they are as an open book.

I understand there are a few in our own country who, by some special endowment not known to the writer, can harness their chariots to lines of magnetic force and ride on ether vibrations to the most distant planet, whose sensitive souls are so delicately attuned to the symphony of the spheres that they can ascertain with minutest detail the throbbings and pulsations that will take place in the family of worlds for a year or two to come, and can tell what the effect will be on the varied interests of mankind for the same period, while there are others in the same line of research weighted down by ponderous calculations and stern realities, who, living at the bottom of the aerial ocean, think they are doing well if they can tell their neigh-

bors when to carry an umbrella or when it may be safe to ship a car-load of fruit.

I have been so situated for some years past that I could not help but feel interested in this intensely interesting subject, for I am bounded on the north by a long-range weather forecaster, Foster, of St. Joseph, Mo., and on the east by another, Hicks, of St. Louis, Mo. What surprises me more than anything else is that, situated as I am, I have not been influenced so far as I know by thought transference or the psychological communications which are supposed to pass between kindred spirits. But to come to the point: Can long-range weather forecasts be made with sufficient precision to be of particular benefit to the public? I have to answer yes and no; at times, yes; at other times, no. I have tried it and met with success; again I have tried it and met with total failure.

I do not think that it lies within the bounds of human knowledge to make definite long-range forecasts under all conditions, but I do think it possible, *at times*, to make a very good general forecast for a week or two with reasonable precision for certain localities. Some sections of the country present less difficulty than others, notably those having well-marked seasons and uniformity of conditions during long periods, such as obtain on the Pacific slope. I have tried to find cycles when weather conditions repeat themselves, but without success for the section of country in which I happen to be located. I have found but little consolation in the sun spot theory, as the years of supposed maximum or minimum frequency afford no index as to what month may be wet or dry, cold or warm. There may possibly be some reason, unknown to me, for the assignment of numerous and destructive tornadoes and electrical storms to the great solar energy assumed to be developed at the time of maximum sun-spot frequency, but it will not hold very well with regard to precipitation. We are now almost at a time of minimum solar energy as measured by sun-spot periods, and yet my section of the country has received from 9 to 12 inches of rain in excess of normal. Some of the farmers in eastern Kansas and northwest Missouri had to plant corn three or four times this year on account of washouts.

Struggling to find something else that might be of aid, I entertained myself for a time with thoughts on lunar influence, only to find that I could not swear by the inconstant moon. I found that the weather was just as liable to be one kind as another during any of the moon's phases or perturbations.

The next line in which I directed some attention was Professor Bigelow's solar magnetic theory of weather changes, and I will say candidly that I got more satisfaction than disappointment out of it. I have made several very accurate forecasts based entirely upon my humble interpretation of his suggestions, which I can not possibly attribute to chance, and I have made others which, on account, I suppose, of the inverse conditions which the professor mentions in his writings, were conspicuous failures.

The last long-range forecast I made was for carnival week at Kansas City, from October 3 to 8. About September 28 I gave out, with slight reservation, that we would be within storm influences which would give threatening weather and some rains from Friday, September 30, to perhaps Monday evening, October 3, when they should pass off. Tuesday, Wednesday, and Thursday, should be fair, followed by

a change suggesting rain on Friday. In addition I stated that the week would likely be very much cooler than the two preceding, and that people coming to town should bring their wraps and overcoats. It affords me pleasure to state that all this was verified almost to the letter. But that offers no guarantee that the next forecast will be fulfilled. When I consider the solar schemes as a basis for forecasting, I am confronted by the fact that unchanging atmospheric conditions frequently occur over widespread areas during the whole time necessary for a complete solar rotation, and during which every variation shown in the average magnetic curve must have occurred, so that it seems as if great irregularities ought to have figured in the average daily solar impress, or else there must be very unequal distribution of earth currents to be acted upon by the solar forces. Coming nearer home, I will now refer to certain atmospheric conditions, doubtless well known to all of you, which appear at times and which make possible long-range forecasts with reasonable hope of verification. The area of abnormally high pressure which settles over the central Plateau region in the winter season, exerts a modifying influence on the temperature of the Western States. Its permanence covers at least one week, and usually two weeks, and frequently more. From the first phase of permanency it is safe to predict that no very cold weather may be expected for a week or ten days, south of Nebraska and Iowa. This condition prevailed during the greater portion of last winter and, as a result, no very cold weather was experienced. On our neighboring lakes ice did not reach 8 inches in thickness. Again, during the summer months the great south Atlantic high which extends over the southeast portions of the country, enables a forecaster to predict with reasonable safety an absence of rain in the West for nearly a week.

The passage of a series of lows, far to the north, in summer, presages several days in advance dry weather for the West. The series may be anticipated by the very weak high which follows the first low, leaving practically a low belt along the British line to the north Pacific, while pressure above normal obtains over the southern portions of the country. Then again, circular "lows," the center of which do not dip south of the northern tier of States, although rather formidable, usually produce hot and windy weather in the West and Southwest, but no rain. These furnish the greater number of stereotyped conditions when it may be reasonably safe to make long-range forecasts from the maps, and are, perhaps, the most reliable grounds upon which to base them. Regarding the seasons, so far as I know, it is impossible to anticipate their characteristics as to weather details. Should one season show a great excess or deficiency of any element, it would be reasonable to expect reversed conditions the following season, but for definite forecasting it counts for little, and the man who relies very much on it may soon have a "yellow" reputation to carry around with him. Long-range forecasting, except on rare occasions, is full of surprises. I would like to grasp the hand of the one who can do it successfully. I think that, some day, within the lives of present aspiring observers great skill will be acquired in this work, but only when we have fathomed the methods of the great universe builder.

Mr. PAGUE. On September 30 I received information from the Chief

of the Weather Bureau that one of the Convention subjects assigned me was, "Can long-range forecasts be made with sufficient precision to be of general utility?"

This I construe to be applicable to me in my work in the north Pacific forecast division of the Weather Bureau, and I answer, yes, without a question or a doubt. I answer yes, for the reason that for the past two years I have been making, by authority, long-range forecasts, and they have been of practical utility and value to the farmers, fruit growers, river men, and vessel men. I know they are of utility and value because I have been told so by many interested people. These long-range forecasts cover periods of from three to seven days, depending upon the season of the year and the clearness or decisiveness of the conditions. Long-range forecasts can be made for a period greater than seven days, possibly for a whole season or half a year, when the chain of stations is extended from British Columbia and the Canadian Provinces northward to Alaska and to the Aleutian Islands on the west. The forecast for a period of ten days or more can then be made with at least as much accuracy as they are now made for thirty to forty-eight hours; and these forecasts can be made not only for the north Pacific division, but for the whole Pacific slope and for the greater portion of the northern half of the country east of the Rocky Mountains. These are statements that I know will be doubted and adversely criticised, but the proof of their accuracy is easily shown.

Not many years ago few storms were given credit for having originated or having been first observed on the north Pacific coast, then moving eastward, losing energy and almost identity in their course across the Rocky Mountains, and regaining energy and perfect identity as they approached the moister air of the Great Lakes. Within the last five years I have been informed by a professor of the Weather Bureau at Washington City that, unless the perfect cyclonic movement of the storm area be distinct and well defined, the storms could not be traced with unfailing accuracy across the Rocky Mountains. To prove the storm area, cyclonic winds must be shown at every station. This is an absurd statement, especially so when local winds, due to the topographical features of the country, constantly prevail, no matter what the barometric depression may be. For example, the winds at Idaho Falls almost invariably blow from a low to a high, and the passage of a storm area across the Rocky Mountains, due to such local winds, was doubted because the cyclonic movement was not distinct or well defined.

A successful forecaster must understand the geographic as well as the meteorologic conditions of his division, and it has been my pleasure to note the following characteristics in the movements of the areas of high and low pressure. As the heat of summer passes away, the areas of low pressure move southward from Alaska to about the forty-eighth degree north latitude, on which parallel they pass eastward, almost losing identity when they cross the Rocky Mountains; but when once as far as the Dakotas they regain energy and move onward. They continue in their comparatively low latitude until the increasing heat of the next summer forces them northward. These are two distinct and well-defined movements of low pressure. The highs, also, have two well-defined movements. The permanent home of the highs is off the southwestern California coast several thousand miles, and the

center moves north in summer and south in winter. The movement is shown on hydrographic charts and in all standard works on meteorology. The summer high moves northeastward along the coast line to about the fiftieth parallel, thence eastward. In winter the high moves northward to about the fortieth parallel, thence eastward, and forms, or helps to form, the permanent high in the plateau region of southern Idaho and adjacent regions, and this is found there during almost the entire winter season. The other movement is the high from the north, appearing first in Alberta, thence moving southeastward to the Great Lakes, frequently giving cold waves to the country east of the Rocky Mountains. These movements of high and low areas are well defined, and when once the subject is followed closely and the causes clearly defined then will forecasts for longer periods be more accurate and of more value. There is a reason for the movements of the lows and highs, and this reason is the stumbling-block to success in solving the problem. The movements are clear, and the reason for the movements may also be clear when discovered. It is the knowledge of these movements that enables me to make the long-range forecast. The lows never appear off the Washington coast during the summer season, nor do the highs appear over the Plateau region in the same season. The movements are regular; hence the success in the present long-range forecasts. The change from the dry to the wet season and from the wet to the dry have been announced by me for the past five years and not one error has yet been made. This success is the reason why I say so emphatically that long-range forecasts are possible and that they can be made of utility and of value.

(g) *Forecast distribution: Should the wording of the forecasts be confined to the vocabulary of the present logotype outfit? Is it advisable to extend the vocabulary of the logotype outfit?*

F. P. CHAFFEE, Montgomery, Ala., and G. M. CHAPPEL, Des Moines, Iowa.

Mr. CHAFFEE. Next to the accuracy of the various forecasts and warnings, the most important subject in connection with the work of the Bureau is that of forecast distribution, so that the valuable information, collected and collated at a great cost, may be quickly disseminated among the people. By the public spirited cooperation of the distributing displaymen, the logotype system has been the means of placing our daily forecasts in nearly every post office of any importance, and in time to be of direct benefit to the various interests of the different sections. The logotype system of distribution has certainly been the best means of familiarizing the people with our work and showing them what we are doing for them. In my opinion the daily forecasts should be made to conform to the logotype vocabulary, so that the distributing agents may not be troubled with interpreting the forecasts, the public interests endangered, and the reputation of the Bureau jeopardized by incorrect interpretation of the official forecasts.

The present logotype vocabulary is ample to cover any forecast or warning, and its extension is not deemed advisable, as the outfit is now so complete and thorough that any addition to it will make it unwieldy and troublesome. The greatest difficulty experienced in

the logotype distribution is in stamping the cards plainly and uniformly. The present logotype holder and inking pad might be improved on by devising a self-inking spring logotype holder with the bed of the holder channeled to receive the logotypes and hold them securely while the stamping machine is being operated. Such machines, it is thought, could be made so cheaply as to justify the Bureau in supplying them to such displaymen as distribute a large number of cards.

"Should the wording of the forecasts be confined to the vocabulary of the present logotype outfit?" I would most emphatically reply yes; and I would right here like to enter a protest against the forecast officials at Washington, or any forecast center, using any word in the regular forecast that is not in the logotype vocabulary.

Mr. CHAPPEL. There is no doubt in my mind that the forecast official can improve his forecast and thereby benefit the public by having an increased vocabulary. Now the forecast official will use the words which come to his mind to express exact conditions, and from that point of view I would be in favor of increasing the vocabulary, but as our cards are distributed mainly by people not connected with the Bureau, receiving no pay, I would not approve of enlarging the vocabulary. If the forecasts were distributed from regular Weather Bureau stations, it would not make much difference, but as a great many more cards are sent out by voluntary displaymen than from regular stations, I do not favor increasing the vocabulary, but would confine the forecast official to the regular vocabulary.

Mr. HAMMON. That is all right for a good part of the United States, but not for the whole. We need different vocabularies in different places. The present vocabulary fails to meet our needs in California, where much wider range of expression is necessary to accurately define the conditions predicted.

Mr. CHAFFEE. In connection with the logotype distribution of forecasts, I have found that it would be good if we could telegraph river forecasts to the river observers and let them disseminate the information in the same way we do our weather forecasts. In my river section in Alabama, in addition to the telegraphic distribution of flood warnings, such information is also widely distributed by mail, and has been of special benefit to farmers and stock raisers in the low grounds of the river basins.

Mr. Hackett thought it would be better to let each State specify its own vocabulary. Mr. Salisbury suggested that in the case of the State furnishing the vocabulary it could, perhaps, be furnished by the official in charge of the forecast center, who ought to know what kind of vocabulary he is going to use. The difficulty to be avoided is that the forecaster in charge of the forecast center has one vocabulary which he varies at his pleasure, but which does not correspond with the vocabulary furnished with the logotype outfit.

(h) River and flood service.

R. J. HYATT, St. Louis, Mo., and L. M. PINDELL, Chattanooga, Tenn.

Mr. HYATT. The river and flood service of the Weather Bureau is of vital importance to a large portion of the people of the United States. By means of the river forecasts, flood warnings, and general information in regard to the stages of water along the principal streams, furnished by the Weather Bureau daily, the people are kept constantly posted in reference to the river conditions and make their calculations accordingly. During the periods of high water the most intense interest is shown in the river and flood service of the Government. At all river stations the office is besieged early and late by the public interested in the river, and all are more or less concerned in regard to the matter either directly or indirectly. The office telephone is kept busy answering calls and giving information to the public during flood period. At all times, however, the data is of great value and much sought by the public.

When the first warning note of impending high water is given by the Weather Bureau immediate preparations for the coming flood are made by the planters, levee boards, railroads, steamboats, and river interests generally. The levees are strengthened and raised if necessary; rafts are constructed and boats put in good condition for any emergency. Stock and other property are moved to places of known safety, such as mounds and highlands in the vicinity, in ample time in advance of the overflow. The people on lowlands subject to overflow naturally look to the Weather Bureau for protection and many precious lives and millions of property have been saved by the warnings issued from time to time. Planters when notified of an early freshet will defer planting until the danger has passed, thereby saving the cost of seed and labor. On the other hand if they know that the stage of water will not affect their land, they will plant an early crop and reap the benefit thereof. From time immemorial the great Father of Waters and his many branches have seen fit to throw off the yoke and go beyond all bounds, during certain seasons, and the ingenuity of man has so far been baffled in coping with the fury of the floods. The conditions, however, bad as they are at times, could be much worse; and during my observation of a number of floods I have always noticed some mitigating circumstances. A combination of high water in the Mississippi and all of its tributaries, in my opinion, has rarely if ever been witnessed, and the problem of controlling such a vast volume of water would be a very difficult one for the Government to solve. During the great flood of 1897, one of the most disastrous of record, I was stationed at Vicksburg, and the demands made upon the river and flood service of the Weather Bureau that year were enormous. Extra bulletins were called for at night and on Sundays in addition to the regular morning reports. The Government sent relief boats with ample provisions for those cut off by the flood from commercial centers, and camps were established for the destitute. The progressive policy of the Agricultural Department in recent years in giving the river forecasts and warnings the widest possible distribution is highly appreciated by the general public and much praise has been given the service by the many and varied interests involved.

The amount of passenger and freight traffic carried on the rivers is almost incalculable, and the river and flood service of the Weather

Bureau is considered a necessary adjunct to the successful prosecution of this important branch of commerce.

Mr. PINDELL. I have not prepared a paper, but have made a few notes which I will use to refresh my memory. I have also distributed copies of the Paper on the Tennessee River and Flood Systems around the room for the benefit of the officials present; the paper shows a study of over ten years of the local data. The benefit of the river and flood warnings to the people of my section is incalculable. It extends all the way from the head waters to below Florence, and we have received requests by telegraph for information from as far down as Paducah. We have given from thirty-six to forty-eight hours warning as far down as Bridgeport, and in the flood of 1897 all the property lost that I could hear of as far down as Florence, Ala., did not exceed \$100. The people in Chattanooga and the surrounding districts rely implicitly on the river warnings given by the United States Weather Bureau. When the Tennessee River reaches 36 feet, readings are taken every half hour and given to the public, for the reason that the water backs into Chattanooga and Chickamauga Creeks, overflows their banks, and forces the people to move out. Thirty-seven families one day awaited an inch more of rise in the water before they would have to move; I told them not to go and promised them thirty-six hours notice, and they were not compelled to move. We have one station on the Hiwassee River which only reports six months in the year; I think that all our river stations should report all the year round. On the Little Tennessee we have no station, and I would like to see one established there. Our river service could be improved by telegraphing daily to certain places desiring river forecasts. As it is now, some of them wait until the river commences to rise and then telegraph Chattanooga for the forecasts.

The rainfall observers should be authorized to telegraph the rainfall whenever it equals or exceeds one-half an inch. It frequently happens that between .90 and .98 of an inch of rain falls for two and three days at these stations and they make no report, consequently the river forecast falls short on the crest rise predicted. The code of the river system could be decidedly improved. I would suggest that the code words in our regular code signal be substituted for those now used in the river code. That would save in telegrams and time of translating. Our river men are as much, if not more, interested in low water than high water from the fact that they only look after and protect their property in high water, while in low water they do most of their business, and if they knew the stages at each river station they could readily decide how to load their barges and boats for safe passage over the sand bars, rocks, etc., that are yet in the channel. For this reason river stations should report the entire year. The lumber interest on the Little Tennessee River is practically unprovided for, there being only a rainfall station at Bryson City, N. C., on the head waters. A river station should be established within 50 miles of the mouth of this river. To better improve the service, every river and rainfall station should be visited by the official in charge of the center at least once every two years, as changes are frequently made and it is impossible to get some of these observers to understand by correspondence exactly what is required and wanted.

If the official and the observers knew each other personally, better work and more prompt service would result.

Mr. MARBURY. I have noticed that in all the papers that have been brought forward the importance of low water has been underrated. For a long time it has been acknowledged that water is our cheapest source of power, and no capitalist is willing to subscribe money for the erection of a factory unless he knows positively that a certain stream of water can be depended upon the year round to furnish power. I know this from an instance that occurred in Atlanta not long ago. There had been no official record kept of the section where they contemplated establishing this plant, consequently they removed about one hundred miles lower down, where we had river observations for ten years back, which established beyond doubt, that they could depend upon a certain amount of water. They have now established a power plant at Columbus, Ga., which will probably run all the electric plants in that city. It seems to me that it is important to keep ourselves posted and keep the river stations open the year round, in order that we may know what low water is, and also that we should work in conjunction with the hydrographic department of the geological surveys of the States. They take these measurements, showing the amount of water passing at certain stages; we take the amount of rainfall; from these data as a basis we can determine the amount of evaporation, the amount of percolation, and the amount that passes off. These records will be of untold value in future years—fully as valuable as the records of floods. I think we should have the observations continued the year round, not so much for predictions as for record. This information is being called for more and more each year.

It is now acknowledged that cotton goods can be manufactured cheaper in the south than anywhere else. Why? Because with our water power near the cotton fields, factories can be, some already have been, located on these favorable spots, and the greater portion of our cotton crop shipped in the form of manufactured goods. Eastern capitalists, seeing this possibility, are already beginning to investigate our region with a real desire of finding out more about it. Now we want to be able to furnish officially the exact condition of our rivers for each day of the year, the low as well as the high water stages, the former being by far more important in this connection than the latter. Power plants can be so constructed as to take care of themselves in high water if it is assured that they will always have the required flow for power.

Mr. Sims suggested that the flow line might be shown on a black-board placed on the paddle boxes of steamers, or on the casing of a stern-wheel boat, so that the boat in passing would show exactly how

the river stood, the official in charge of a division of a river to place the drawing on a board for the section covered on the up or down trip of the boat.

(i) *Should warning messages (Form 1043 C) be of some distinctive color to more readily attract attention?*

S. W. GLENN, Huron, S. Dak., and T. B. JENNINGS, Topeka, Kans.

Mr. GLENN. The Form 1043 C now in use is the same color as the daily mail forecast card, and there is nothing to distinguish it from that card and indicate its greater importance to the public but the printed descriptive matter on it. To the person who daily inspects the forecast cards this is sufficient, but there are many interests, at least in South Dakota, not materially affected by ordinary changes in weather and temperature, to which cold wave or norther warnings are, or might be, of importance and benefit. If Forms 1043 C were of some distinctive color, they would more promptly and generally attract the attention of the masses, and thereby prove of universal value. In South Dakota and probably much of the Northwest there are live stock, creamery, and probably other interests not specially benefited by the ordinary forecasts to which, in many localities, the cold wave and norther warnings are of great importance. Many farmers in South Dakota hasten from the towns to their homes when they see these warnings to provide against loss or damage, and the number would probably be greater if the color of Form 1043 C was such as to attract special attention. It has been found that Railway Mail Service clerks are frequently asked at depots what the weather forecast is. A card of a distinctive color for warnings would at a glance put the clerk in possession of weather information of importance to the public which might otherwise escape his attention, and he would find interest in disseminating information of such importance wherever possible, especially to railway employees and habitues of depots. The postmaster, if hurried, may neglect to post the ordinary mail forecast card in its bulletin board until the entire local mail is distributed; if the card was of a distinctive color to indicate its importance as a warning, it would immediately attract attention, and its importance to the public would no doubt cause him to give it publicity immediately. The norther and severe cold-wave warnings are of such importance to the railways of the Northwest that the assistant superintendent of the Chicago and Northwestern Railway at Huron has agreed to disseminate them by telegraph to agents of the entire system in South Dakota, when practicable, without expense to the Government. They are of such importance to the masses that I am satisfied the adoption of Form 1043 C of a distinctive color for each class of warnings, different from the color of the ordinary daily forecast cards, would be of more benefit to the public generally, and more promptly and generally disseminate the information than the form now in use for the purpose. In the case of cold waves, they could take the place of the present Form 1044-Met'l to advantage by facilitating local distribution. The public could very readily be instructed as to the significance of the cards of different colors.

Mr. JENNINGS. In 1871 the Signal Service, in addition to the regular "probabilities," adopted a special flag to warn mariners of the

approach of storms. The importance of this flag soon became so prominent that vessels leaving port during its display forfeited their insurance. In 1884 a white flag with a black center was adopted as the special warning of the approach of cold waves, and the importance of this flag in the interior soon became as pronounced as that of the storm flag on the coast, so that to-day the forecast may contain the announcement of a cold wave without causing much more than a ripple in the public current, but fly the cold-wave flag to the breeze and note the change. Now all is bustle; the cattle man looks after his herds; fruit in transmission receives extra care; the farmer hastens home to care for his stock; the produce and commission merchants take extra precautions; and so I might name nearly every industry.

If a distinctive flag is so important on the coast with reference to storms, or over the whole country with reference to cold waves, how much more important is it that Form 1043 C, which combines both and reaches hundreds where the flag reaches one, should be distinctive.

What this distinction should be I confess I am not prepared to state, but believe that a distinctive color would best subserve the end; yet it should be a color that would not interfere with the legibility of the ink used. Such a card would soon become more widely prominent and better known than either of the flags, so that when posted the news would soon spread over the town and through the surrounding country, "the red card is out and a cold wave is coming," or "look out for twisters," as the case might be.

It is very desirable, I might say imperative, that Form 1043 C be distinctive.

TOPIC No. 3.—PAPER: RELATION OF THE WEATHER BUREAU TO THE DEPARTMENT OF AGRICULTURE.

E. B. CALVERT, Washington, D. C.

MR. CALVERT. There are three things, more than any other, upon which the prosperity of a nation depends: its climate, agricultural products, and mineral deposits. It is difficult to conceive of a progressive and wealthy nation without these natural resources. The products of the soil and the earth beneath the soil give life to the people and are the basis of commerce and manufactures. But however rich a land may be in soil and minerals it can not reach its fullest development unless the climate of that land is favorable. In our own United States we have all the conditions for a prosperous nation.

Nature was here so lavish of her store,
That she bestowed until she could bestow no more.

The work of the Weather Bureau is so closely interwoven with two of the great factors of prosperity that we have named, climatology and agriculture, that one can not be considered without the other. If the climatology of a section is accurately determined, the scientific agriculturist knows what crop the lands will bring forth in greatest abundance. Experience has been called our great teacher, but something else is required of the successful agriculturist. He must get close to nature and learn her secrets. It is not sufficient for him to know that a certain piece of land produces an abundance of one kind

of grain, while another farm product can not be grown thereon. He must know why these things are so; he must understand the composition of the soil he cultivates, how much rain annually falls on his possessions and the movement of this moisture in the soil; he must be familiar with the nature of the economic plants, the plant foods required in growing and maturing them, and the amount of moisture and sunshine necessary for perfect maturity. Climatology is surely a part of agriculture.

The United States has a Department of Agriculture, the most complete in the world; and at its head is a practical farmer, a scientific farmer—one who has guided the plow as the furrows were turned, and one who has studied the science of agriculture in Nature's laboratory, as well as in his own. Under him serve what Sir Richard Armstrong, of England, declares to be the ablest aggregation of agricultural scientists to be found anywhere in the universe.

The home seeker obtains from the Weather Bureau information as to the climate of any State or county in which he wishes to locate; the divisions of soil and chemistry inform him as to the nature of the land he will cultivate and what crops will best thrive thereon; the botanist and vegetable pathologist name the flora and the diseases to which plants are subject, and give a remedy for them; the agrostologist advises him as to the grasses to be sown for feeding his flocks; and the Departmental publications keep him abreast of the arts and science of farm work as it expands and develops. The Department of Agriculture is an intellectual monument of which the people can be justly proud—a monument built of divisions and bureaus whose functions are separate and useful, yet working together in one harmonious whole. The Weather Bureau is a part of this grand monument. A portion of its work necessarily has only a remote connection with agriculture, but along certain lines its identity with the Department is clearly established. This is particularly true in regard to climatology and its climate and crop work. The botanist, biologist, agrostologist, agricultural chemist, and soil physicist, all understand and appreciate its value. It is just as necessary for the Weather Bureau, through its section directors of the State Climate and Crop Services, to have a certain knowledge of the work done by these scientists as it is for them to understand something about climatology. The section director is better fitted to intelligently report on the crops of which he writes if he understands these things. It is all a part of his work. He can aid the soil physicist, botanist, and chemist, while they in turn impart to him useful knowledge. A successful forecaster in the Weather Bureau, in addition to his knowledge gained by experience and empirical reasoning, must know the physical laws connected with the meteorological conditions he foretells. Just so, the section director, in addition to his skill as an executive and his ability as an organizer, should understand the principles of agricultural chemistry, and the physical requirements of the staple crops. This knowledge raises him above the plane of a mechanical worker to the eminence of a practical scientist and student. The climatological and agricultural field is large. Our knowledge of it is but as a grain of sand on the ocean shores, compared to that which has not yet been acquired by man. But Nature holds her secrets with jealous care. She only reveals her jewels to those who with concentration of physical and mental energies earnestly dig down into her depths.

There is legitimate work in this line to be done. It behooves the officials of the Weather Bureau to remember that we are but an integral part of a great Department, and that we should become acquainted with the aims, objects, and developments of the other branches to the end that we may grow together, one assisting the other, into a perfect organization.

TOPIC No. 4.—WEST INDIAN HURRICANE SERVICE

Prof. WILLIS L. MOORE, Washington, D. C.

Professor Moore spoke briefly on the West Indian Hurricane Service as follows:

The West India region, which includes an area as large as the United States, is to-day brought twice daily under an atmospheric survey that will enable us in the future, as it has in two cases recently, to detect the development of the most destructive storms that visit our continent; to measure them in their inception, to keep pace with them as they cross the Windward Islands and come up through the Caribbean Sea to the Gulf of Mexico, and to do what has been the dream of the meteorologists of England and other scientists for a great many years—to warn the commerce of all nations in that great region against hurricanes. It was a singular thing that this year no hurricane passed over the Antilles until several weeks after the beginning of the usual hurricane season. Providence seemed to be on the side of those who fought against the oppressors of humanity. Our fleet was able to leave those waters without encountering a storm that even incommoded it. Soon after its departure there came a most destructive storm; one in which it seemed that the force of all the storms that should have developed in the preceding weeks was gathered and centered. It seemed that nature was keeping up the average and establishing the equilibrium by letting the winds burst in one terrific hurricane after the American fleet had sailed north.

I wish to call attention to the warnings issued in advance of that great storm; they could not have been more advantageously displayed in the interest of the mariner had we possessed absolute foreknowledge of the development and severity of the storm.

TOPIC No. 5.—POSSIBILITIES OF THE WEATHER SERVICE ON THE PACIFIC COAST. VALUE OF MOUNT TAMALPAIS OBSERVATIONS.

W. H. HAMMON, San Francisco, Cal., and B. S. PAGUE, Portland, Oreg.

Professor MOORE. We will now hear from Mr. Hammon as to the possibilities of making seasonal forecasts of rainfall for the Pacific Coast States.

Mr. HAMMON. I think what Professor Moore refers to is a paper on the Rainfall of California and the Weather of the Aleutian Islands, which he requested me to present here, but which I do not think it feasible to read in detail. It really belongs more in the line of long-

range forecasting. I want to say just a word in presenting the paper, and ask that it be referred to some committee for consideration.

Conditions on our coast are quite uniform, with once in a while, and at long intervals, marked exceptions. Four times in the last half century we have had one-half, or less than one-half the normal rainfall in California. It struck me that such conditions must be associated with marked conditions elsewhere as a cause. In searching for these I found that when the conditions are abnormally warm at Unga Island, Alaska, where we have a voluntary observer, then three months later the rainfall in California is abnormally light, and when the conditions there are cold, the rainfall here is excessive. I searched for further information, and found records at some four or five islands, taken by agents of the Alaska Commercial Company. The records are not very well taken; some of them by Indians. Some ran for three years, some for ten. The aggregate number of years is about twenty-five, and together they cover a period of thirteen years. Using the hypothesis based on the first four years' record, and testing it by these other records, I found that 74 per cent of the abnormal rainfall in California was preceded, for a 3-months period, by abnormal temperature conditions on the Aleutian Islands; that is, when it was warm up there there was light rainfall, according to the rule, three months later in California, and *vice versa*. The original Unga Island records made 79 per cent. I have all the facts and papers in this connection with me, and I suggest that a committee be appointed to consider the matter and ascertain whether there is anything in it. The people on the Pacific coast would be glad to have the matter receive attention here and have some action taken. On the general subject assigned me I submit the following:

Owing to the reputation for exaggeration which eastern people have unjustly accredited to residents of the "Golden West," I hesitate to speak *facts* before even so well informed a body on climatic matters as this Convention. To give to the imagination that play the subject warrants would be but to court incredulity.

The Pacific coast is peculiarly a region of climatic extremes. It is the region where may be found the places of maximum and almost minimum rainfall and the highest and nearly the lowest temperatures for the entire United States. Places with mean annual rainfall as low as 3 inches may have floods that will annihilate towns and wash away miles of railroad track. In certain counties exist living glaciers and also temperatures above the limit of human endurance. The vegetable products are, of course, as varied as the climate. On the Sierra are places where even the red snow plant will not grow, and yet 50 miles away palms flourish in profusion and alfalfa yields six crops a year. Surely a region with so varied climatic conditions and so many resultant industries must be a field where the Weather Bureau can do a valuable work.

The Pacific coast is recognized as one of the great wheat-producing regions of the United States. Over a large portion of this region

there is sometimes insufficient rainfall. At times, on such occasions, a rain forecast will change the price of wheat several cents per bushel. Portions of the most productive regions are in the vast river bottoms, which are subject to overflow in times of excessive rainfall, with consequent loss of entire crop. At other times frosts and again dessicating "northers" do marked injury.

Should the suggestion outlined in another paper as to the possible relationship between temperature conditions in the Aleutian Archipelago and rainfall on the Pacific coast prove to be a fact, and the ability result therefrom to make forecasts of abnormal rainfall two or three months in advance, as now seems possible, the profits to the grain industry will be more than doubled.

What is said of wheat is still more true of barley, which, being more of a local crop, has the price much more affected by local conditions. Two years ago about one-third of the entire crop of barley raised in the United States was grown in California. The failure of the crop during the past season increased the price in that State 300 per cent. One of the largest growers and commission merchants on the San Francisco Produce Exchange failed because a telegraph operator mistook an "s" for an "l" in the cipher report from Eureka, thus changing a northwest-wind word to that for half an inch of rainfall at that point.

But it is in fruit industries that the Weather Bureau can be of greatest benefit. In no other section of the United States are there so varied or extensive orchard industries, and the present is merely a forerunner of what may be expected, in a much more marked degree, in the future. Reference is made especially to California and portions of Arizona with which the writer is familiar. With the improved transportation facilities now in sight and the reduction in freights which will result from competition, the excellence of its products, the extent of the industry, and the effects of its competition will surprise the whole world. Without the warnings of the Weather Bureau many of the fruit industries would never have reached their present magnitude, and their future extension will in a considerable measure depend upon the aid rendered by this service.

All have doubtless heard of the work that has been done in warning raisin and prune driers of the infrequent summer rains which do such serious damage to the unprotected crop. With the generous use of the telephone and telegraph and the cordial co-operation of the railroads information useful to the forecaster is received as desired; warnings are delayed until he is practically certain of the result, and then distributed in such a wholesale fashion that almost every drier in the affected region will receive the warning in an hour from the time it is issued. This line of work has reached such a degree of excellence that but little further improvement is expected or needed. Hardly a single failure in the warnings has been noted in the past five seasons. Single warnings have been of more value than the annual cost of the entire Pacific coast service.

The chief enemy to all lines of fruit industry, however, is frost. The temperatures in the principal fruit growing districts of California are somewhat peculiar from the fact that while, at no time in the year, are air temperatures below 24° to 26° to be expected, and the absolute minima ever recorded are but 5° or 6° lower, yet frosty conditions are likely to occur at any time from November to April, in-

clusive. Probably never a year passes when the losses from frost do not exceed the profits or, in other words, the profits would have been doubled had the injury from frost been prevented. To prevent this loss it is necessary that the fruit grower be taught *how* to protect his crop, as well as informed *when* frost is likely to occur. In this particular I believe the people of the Pacific coast, especially the orange growers of southern California, are perhaps better informed than in most other portions of our country, but decidedly more instruction is necessary. Not only should articles be written and pamphlets issued on this subject, but it is necessary if possible to give personal instruction to the grower. This topic should be one of the leading ones to be discussed at the farmers institutes now so generally conducted throughout the country.

It has been possible to forecast frosts in a fairly satisfactory manner for a considerable time, but owing to the very generous treatment of the Pacific coast by the Department of Agriculture and the present Chief of our Bureau this year, a decided advance in the accuracy of these forecasts is expected. Several years ago it was observed that the cool waves of the Pacific coast followed the movements southward of a wave of falling pressure. I think the Chief of the Bureau observed this condition first with reference to cold waves in Wyoming and Colorado. It has been possible to follow these pressure waves as they moved southward through Idaho and until they passed Winnemucca and Salt Lake City. From the time they passed those stations, however, they were lost sight of until they appeared with their frosty effects in California and Arizona. In fact as good, and perhaps better, frost forecasts were possible for that region thirty-six and forty-eight hours in advance than could be made for a shorter period. The opening of several stations in the Transrocky Mountain region will be of great value in frost predicting.

The station recently established on Mount Tamalpais, near San Francisco, is another great aid to frost forecasting. Among many other benefits expected from that station may be mentioned the fact that every marked temperature change which has occurred in California and the Plateau region to the eastward during the past year has been preceded about twenty-four hours by a falling temperature upon the mountains. I am unable to give a satisfactory explanation of this phenomenon, but its occurrence has been so frequent as to leave no room for doubt as to the fact. The place is also an ideal point for weather observations. At San Francisco, for six months of the year, there is a large portion of the time that the observing station is immersed in a local fog with west wind, and to a less degree this is true during the other six months. The station on the summit, half a mile above the sea, and three or four miles from the coast, is above all these disturbing influences. Gales on the mountain are due to general cyclonic disturbances and are an indication of rain. Observations at this station I think have already shown quite conclusively the cause of the fogs of the Pacific coast.

It has brought to light many facts of interest to the meteorologist, one of the most striking being the marked temperature inversion between the mountain top and the valley. During the summer the temperature on the mountain averages more than 10° higher than in the valley.

The station is being equipped as a complete self-registering observa-

tory. It is connected with the San Francisco office by both telephone and telegraph, and through it is therefore in immediate connection with the city telephone exchange and the Western Union telegraph office. The observatory building is a convenient 8-room cottage, and has besides office rooms, living quarters for the observer and rooms for the forecast official when he deems it advisable to be upon the mountain and make and issue forecasts therefrom.

But not alone to the agricultural interests of the Pacific coast is or can the Weather Bureau be useful. Throughout the entire coast region from Alaska to South America vast mining operations are carried on. In hydraulic mining, hills are washed away by the force of water power. River bottoms and immense tracts of bottom-lands are scooped up by huge steam dredges, the gravel washed, and the refuse dumped out behind. In all such enterprises information of sudden rises in the stream and of snow in the mountains is of great value.

One of the great drawbacks of at least the south portion of the Pacific coast, in an industrial way, has been the extremely high price of fuel, and the consequent expense of power for manufacturing enterprises. Bituminous coal costs in California from two to three times as much as anthracite does in Pennsylvania. Within the past few years several expensive enterprises have been put in operation for utilizing the water power of mountain streams to run electric dynamos. The electric power thus obtained is carried in high potential currents to cities many miles away, where it is used for manufacturing purposes, to operate street cars, electric lighting, etc. The records of rain and snowfall are eagerly sought by the promoters of these enterprises to determine the probable minimum discharge of the various streams. Warnings of freshets and floods are also much desired.

Similar information is sought by the companies conducting vast irrigating operations, which are causing the deserts in portions of the arid regions "to blossom as the rose."

As yet no mention has been made of the marine industries and the study of climatic conditions, since these are already more clearly understood. In few, if any, sections of the world is there such a variety of climate within the same limits, and it is difficult for people not on the ground fully to understand these conditions and their needs. More instruments, more records, and more study is necessary to properly determine the conditions of Tulare and Inyo counties of California than is necessary in the whole of vast States in the interior valleys of this continent.

Probably no branch of the work of the Bureau on the Pacific coast is so imperfectly and unsatisfactorily performed as that which touches the marine interests. With no observations from the west and with ports at "magnificent distances" apart, storms appear on the ocean which for severity are seldom if ever equaled on the Atlantic. The Pacific is a sad misnomer to that portion of the ocean north of the fortieth degree of latitude, a fact not appreciated by the great majority of the people. The disasters which occur in that ocean in proportion to the vessels engaged are not equaled elsewhere. Vessels at sea feel the effects of these storms before the evidences of them are visible on the coast, and it is only at times that vessels about to leave port can be forewarned in time.

When commercial and industrial enterprises render telegraphic

communication with the Aleutian Islands necessary, or some man of foresight sees that these lie on the shortest route, offering numerous islands for landing places, making this the most feasible route for connecting the United States with the Orient and her recently acquired or expected possessions in the Philippines, then will a new era arise in the work of the weather service on the Pacific coast. Of course such a connection is not to be thought of for Weather Bureau purposes alone, although its benefits might annually approximate its cost.

With the station on Mount Tamalpais multiplied many times on the Cascades, Sierra, and Coast Ranges, and with observatories established on Ranier, Shasta, and Whitney, even in the upper half of the atmosphere, then these mountain chains which now so confuse the forecaster may, and I believe will, become his greatest helpers. During the present administration this long neglected section has received most generous treatment, but similar munificence must mark the actions of Congress and the executive officers of the Department of Agriculture and the Weather Bureau for some years to come. I believe the Pacific coast is the ideal field for Weather Bureau work, and when the work of that section is placed in the prime condition that the not far distant future will find it, then, if not before, it will be found, what already I can dimly see, *that the key to accurate forecasting in the East lies in the weather conditions observed on the Pacific coast.* Every dollar spent in improving the work there means many dollars saved by improved warnings to the eastward. We are all a part of one vast service operated for the benefit of an extensive and rapidly broadening country in which an improvement of one section means a general advance, but in an especial and peculiar manner does the development of our work to the westward mean a resulting decided advantage to the region to the eastward.

Professor Moore (referring to the rain warnings for the raisin-growing district in California) asked if the topography of the country accounted for the accuracy with which forecasts of rain could be made.

Mr. HAMMON. The first point is this, that we wait until we know what is going to happen, and then the railroad, telegraph, and telephone companies let us use their lines to any extent we desire. We can get reports every hour if we wish. We have never given less than six hours warning, and have given as high as twenty-four hours. We never give it until we are sure. We have never sent a warning into the valley that has not been verified. There have been some thirty or forty sent in since I have been on the Pacific coast. The people depend upon them absolutely. Within one hour I can distribute throughout the whole raisin-growing section a warning that will reach almost every grower. There are about sixty blue (rain) flags in that section. We use the telephone, and the exchanges warn every individual over the telephone. These sixty displaymen run up their blue flags, and in one hour it is done.

Professor MOORE. It has been the dream of meteorologists for all time, or at least since cyclonic storms began to be studied, to forecast the weather months or seasons in advance. So far it has not been possible to attain that desired object. I wish to state in this Convention that we do not believe that any man to-day can foretell the weather one month in advance. We believe there is not a shadow of scientific basis for any such prediction; we believe that any long-range forecaster, unless perhaps he be in India, is a fraud and a charlatan. If there were any basis for such predictions, surely we would make use of that knowledge.

Now, I am not discouraged in hoping that the time will come when we may make long-range forecasts. What a wonderful conservation of human energy would result were we able to say to the cotton-grower, "Cotton will be favored next year;" or to the corn and wheat raisers, "You can cultivate prodigiously, for Nature will be bountiful next season!" If the knowledge necessary to make these forecasts ever comes, it will result from a comprehensive study along strictly scientific lines of the great mass of data we have been collecting over a broad area for the past twenty-seven years. No other country in the world has such an extensive area right in the very track of storms, in the middle latitudes, that is twice daily brought under a synoptic weather survey. We, possibly, are collecting data which will be of vast utility to the coming civilization, and which will be an important factor in the development of that civilization. This country is leading the world in this study, as it is leading it in a great many other things. It has occurred to me that the civilizations that have come from the north temperate zones have been the civilizations that have endured. When they have reached a high degree of cultivation, they have not become weakened by luxury and gone down to decay like the civilizations of the ancient Egyptians, the Assyrians, the Babylonians, the Medes and Persians, the Greeks, and the Romans. We have made a civilization that has never halted; and from the present indications the Northmen, meaning the men of the north temperate zones, will dominate the earth. And their power comes more from climatic conditions than from geographic situation.

I may be digressing a little, but this civilization of which I am talking is being brought about by the study of just such great problems as you men are engaged upon to-day, and this problem of long-range forecasting is a very important one. Mr. Hammon has made a very intelligent study and it demands our attention. It means a great deal if we can foresee for the Pacific coast the rainfall for the coming season. I will appoint as a committee to take his paper on the rainfall of California, etc., and carefully digest it for final report to the Chief of the Bureau, Professors Abbe and Hazen, Mr. J. War-

ren Smith, Mr. Cox, and Mr. Salisbury. I would like to get the opinions of these gentlemen in writing for final consideration. In this connection I want to say that Mr. Hammon is entitled to a great deal of credit for the method he has employed to bring out the facts and open a discussion which may blaze a way that will lead to important results on the Pacific coast. We wish to hear from Mr. Pague on this same subject. He has made a most intelligent study of the peculiar types of barometric distribution that bring rain on the north Pacific coast. He has been a long time in the region, and has brought his services to a high degree of efficiency. He needs no further introduction from me.

Mr. PAGUE. Before taking up the "Possibilities of the weather service on the Pacific coast," it might be well to stop a moment and consider the peculiar conditions that obtain there. They are peculiar from two points of view, meteorologic and topographic. We have, from the meteorologic standpoint, an immense area of high pressure off the southwestern California coast, which has a slight movement from winter to summer and from summer to winter, north and south. We have over Arizona, portions of California, Nevada, and Utah, a region of low pressure, present in summer and not so distinct in winter, although present to a certain extent over southern California and Arizona. We have a permanent low pressure over what we are pleased to call Tatoosh Island, more specifically described as off the northwestern coast of Washington, and off the British Columbia coast. This area of low pressure, or permanent low, is present from the time we are pleased to call the winter storm conditions until their disappearance the following spring. Possibly we shall determine the origin and entire movement of these lows when we have a system of telegraphic reports stretching from the Philippines to Japan and thence to China, the Russian coast, along the Aleutian Islands to Alaska and finally down to the Pacific northwest. We shall not be able to increase the accuracy of our forecasts to any great extent, nor shall we be enabled to make them for a greater period than we do now, until we have a more thorough system of reports on the north, northwest, and partially to the northeast.

Our storms in winter, from the observations at hand, are first shown off the British Columbian coast. I presume that these areas of low pressure come from the China sea, move along the Aleutian Archipelago, thence along the western coast of North America to about latitude 50° north, where they have a permanent home and a pathway for passage eastward. A few of them are deflected southward along the coast; in the last five or six years several of these areas of low pressure moved southward past Cape Mendocino over California to Arizona and thence northeastward, giving to the eastern portion of the country the most severe storms of that period. These we are pleased to term erratic lows. The low in its regular course moves to about the latitude of Puget Sound, passes eastward about Spokane, north to Alberta and thence toward the Great Lakes; while the area of low pressure is doing this, the high pressure comes in from the southwest, evidently from the immense area of high pressure already referred to, moves from Cape Mendocino to Salt Lake City,

giving to that region an area of high pressure. These are two distinct types of weather we have in our winter season.

In summer we have areas of high pressure which, instead of moving eastward to Salt Lake City, or Southern Idaho, move northward to about 50° north latitude, thence passing eastward. The lows in summer, instead of moving along the western shores of our continent, cross the Rocky Mountains about the latitude of Sitka and come down on the eastern side of the Rockies.

The foregoing are well-defined movements, and on these movements forecasts for greater or shorter periods are possible. I agree with our chairman that long range forecasts are not to be recognized by the Bureau, and that the individuals making them have no standing, but at the same time I want to impress upon the officials of the Weather Bureau here present that we can and do make seasonal forecasts for the north Pacific region which, for the past five years, have yet to be found lacking in a single character for verification. Possibly we can make them more specific in time; we hope so, through the work on which Mr. Hammon is now engaged. Whenever it is found that an area of low pressure comes down along the coast in the autumn, becomes central about Tatoosh Island, we find coincident with that an area of high pressure moving not much farther north than Cape Mendocino, and then due east to Utah, when these conditions are present, then we announce the first winter storm conditions and from that time until the appearance of summer weather conditions next spring, we may expect more rain than fair weather. That is what I am pleased to term a long-range seasonal forecast. That marks the commencement of our rainy season, and yet we don't mean that it will rain all the time, simply that the conditions are more favorable for rain.

Conditions that produce rain in winter will not produce it in summer, and the contrary is also true. In the spring of the year, when we find the high pressure moving northward along the coast to the Columbia River and farther northward to Puget Sound, and an area of low pressure does not appear west of the mountains, we announce that the summer conditions have arrived, and that from then to the commencement of the winter conditions in the autumn, we shall have greater probability for fair weather than for rain. These are general statements, but they are of benefit to the farmer. Many farmers of the Pacific northwest write, and many make personal inquiries, asking whether our rainy season has commenced. They want to know so as to determine whether to begin plowing. Many merchants and many builders ask the same question. So that while the forecast is very general in its terms, its benefits appear on its face, and the same is true of the summer conditions in spring. Many a dealer in wheat asks as to the possibilities for more rain during May and June. We have in the Pacific northwest a country larger in area and richer in resources than many of you have any idea. We have one river, the Columbia, which drains a region approximating one-quarter million square miles; and we have others besides. In that region we have immense wheat fields, that produce from twenty to fifty or sixty bushels per acre, with less than 20 inches of rainfall annually. We have immense timber resources; immense areas devoted to wheat, to hops, and to many other products peculiar to the north temperate zone. All these are affected directly and in-

directly by the Weather Bureau forecasts and warnings. We have an immense coast line and immense shipping. Our trade goes to Russia, China, Japan, the Sandwich Islands and the Philippines, to the South American coasts and around the Horn to the Atlantic side and to Europe. So we must have accurate forecasts, that our ships in leaving the harbors of the Northwest may be enabled to pass outward with assurance of fair winds to start on their long voyages.

Our forecasts cover quite a number of industries. Fortunately the Weather Bureau has a system of telegraph lines extending westward to the capes, so that the storm signals ordered up from Portland are quickly transferred to the various ports of the sound and thence down the straits, so that a ship may stop within five miles of the ocean itself. It is no unusual thing to get requests from consignors or captains for information as to whether their ships may sail. The Columbia River runs 13 miles north of Portland, and through the center of the city flows the Willamette; vessels load in Portland to 23 feet, proceed down the Willamette to the Columbia and thence to sea. Ships going down stop at Astoria, and it is somewhat unusual for a single day to pass without our receiving requests from owners or consignors for information as to whether their ships can pass out.

The Willamette River has its rise in winter, due to melting snow in the Coast and Cascade mountains; the Columbia has its rise in June, due to melting of snow in the Rocky Mountains. The rise in the Willamette is quick, and sometimes very decisive. The river is 150 miles long, and it is sometimes very difficult to give warning for the benefit of the merchants in the city of Portland. The river has but a slight rise to make before the lowest docks are covered. With the rise of the Columbia in June the Willamette can not flow, and hence we have backwater in Portland; we have had 33 feet. In these river forecasts the merchants along the river front will telephone us and say, for example, "We have 4 inches to go upon; shall we move our goods?" If we say no, they leave them; if they have a foot to go upon and we advise them to move their goods, they do it. One hundred thousand to half a million dollars are saved every year by our river forecasts alone.

It is doubtful if any other portion of the United States offers greater possibilities for the weather service than the Pacific coast. The acquisition of new territory in the Pacific, the development of Alaska, and the consequent development of the transmountain States on the Pacific, opens a broad field for the weather service. The good work of the Weather Bureau in the east in connection with the satisfactory work on the coast causes the coast people and those settling among us, who come from the east, to look to the Bureau for much assistance. New lines of steamships are starting from every port; the grain fleet is rapidly increasing; the flour and lumber trade with Siberia and the Orient is very large and it is just commencing, so that there is a large and growing field for the Weather Bureau in the shipping interests of this coast.

The fruit, grain, vegetable, hay, hop, and fishing interests are large and rapidly growing, and in these interests there are many avenues in which the Bureau can be of value. The mining interests are second to none, and as they depend to a very large extent upon the water supply, the value of forecasts and data is apparent. The stock interests represent millions of dollars, and the forecasts and data are

very valuable. It is unnecessary to outline the various means used to serve these interests, for they are familiar to the Weather Bureau official; sufficient to state that they are now large and growing interests, and to cope with them the Weather Bureau must expand and be alert. It has kept pace with all necessities in the past and promises to be equal to or ahead of them in the future.

The river forecast work is second to no other feature of Weather Bureau work on the coast. River forecasts depend upon weather forecasts; an error in one usually results in an error in the other, for melting snow, as a rule, causes the rivers to rise, and upon the temperature and weather conditions the snows remain or melt. The accuracy and value of the river forecast work has frequently been shown by official reports on this subject; sufficient here to state that there is official knowledge of one month's river forecast saving \$240,500 in the city of Portland alone.

The work of the climate and crop service is of great importance. The furnishing of data for physicians, investors, and for immigration purposes is valuable to the people. There are so many ways for the Bureau to aid the public, to grow and develop, on the Pacific coast, that it would become tedious to enumerate them all; sufficient have no doubt been mentioned to illustrate the breadth of the practical work of the Bureau on the coast.

The great need and desire is to furnish more accurate forecasts and for a longer period of time. As our chairman has stated, it has been the dream of meteorologists for all time to forecast the weather for months or seasons in advance, and a study of the meteorology of the Pacific, from the Arctic regions to the equator, from the eastern shore of the Pacific to the western, will, in my opinion, materially assist and possibly accomplish this great desire. The influence of the barometric conditions, arising in the Pacific, extends in a large percentage of cases, if not in all, to the weather conditions east of the Rocky Mountains.

A study of the causes producing, at times, peculiar meteorological phenomena will aid the eastern forecaster as well as those of this coast. This is the great possibility of the Weather Bureau on this coast, but it can not be accomplished until the telegraph lines and observation stations are extended, and the whole coast to the farthest island of the Aleutian Archipelago, the eastern shores of the Orient, and the islands of the Pacific are brought under the present twice-daily atmospheric survey, as is the case in the United States proper.

In the pamphlet prepared by my colaborer, Mr. Blandford, and myself, and issued one year ago, entitled *Weather Forecasting and Weather Types on the North Pacific Slope*, the regular movement of the area of high and low air pressure and the resulting weather are discussed. This pamphlet touches upon the subject of long-range forecasts and briefly outlines how the idea can be enlarged and improved upon. Owing to the well-defined movement of the barometric area on the Pacific slope, I am of the opinion that there is the place where long-range forecasting can be taken up. Causes producing the movements must first be studied; then the effects can be forecast. The present development of the Weather Bureau is rapid, and under the impetus that it now has I am hopeful that my great desire for long-range forecasts will be realized, thus benefiting man-

kind and developing the greatest possibilities of the Weather Bureau on the Pacific coast.

TOPIC No. 6.—PAPER: SOME RAIN PRODUCING PROCESSES.

Prof. E. B. GARRIOTT, Washington, D. C.

As the capacity of air for moisture is increased with rising temperature it is evident that rain or snow can not fall from air that is growing warmer; and yet, paradoxical as the statement may appear, rain usually begins and snow commonly falls with rising temperature. Nevertheless the fact as first stated holds good, for in the upper regions of the air, where the water vapor is actually condensed into rain or snow, certain processes are developed which are not appreciable at the surface of the earth.

The development of one of these processes is dependent upon the warming of the lower air which, in a general way, is accomplished by the radiation of the sun's heat from the earth's surface, a constant operation which is especially active in fair or cloudless weather. In the rain and snow producing processes referred to, however, the warming of the lower air is effected mainly by a northward flow of air having the temperature of warmer latitudes. Obeying the law of cyclonic wind circulation the warm lower currents, which flow from the south in the east quadrants of areas of low barometric pressure, *underflow* colder upper currents from the west and northwest.

As a result of these movements of the lower and upper currents, and of the lower surface temperature in the higher latitudes, a body of warm, moisture-laden air is accumulated beneath masses of colder air. As a matter of fact the warm air flows into an atmospheric pocket, which is lined on all sides save the south with colder air, with the coldest side on top. And it is on the coldest side of the pocket that the moisture in the warm air is first condensed into rain or snow; on the other sides the differences in temperature are not so marked, and clouds only, are formed.

In winter the operation of this process is shown when snow closely follows the passage of a cold wave; and it is well to note in this connection, that the process is operative only in districts covered by the sweep of the cold wave, and that in cases where the low temperatures are carried far to the south of a district, cold, and not warm, air is drawn from the southern latitudes and a temperature gradient, sufficient to produce precipitation in the form of rain or snow, is not established. Investigation shows that many unexpected snowstorms have been produced by this apparent cause, and also discloses instances wherein snow has been expected when the conditions governing the process have not been fulfilled as regards the geographical extent of the cold wave.

During the warmer months rain does not so closely follow the shift of wind to southerly in the wake of high barometer areas; it awaits a nearer approach of the center of the succeeding low barometer area, and the colder upper currents appear to overflow the central storm area and have a more active part in the rain producing process; in other words summer rains are apparently produced by the descent of colder upper currents in the south quadrants rather than by an under-

flow of warm air in the east quadrants of areas of low barometer. In apparent accord with these conclusions the precipitation of the warmer months is confined largely to districts lying south, and in winter to districts lying east of storm centers. To be more definite the heavier summer rains fall in the southeast, and the heavier winter rains or snows in the northeast quadrants of areas of low barometric pressure.

In further considering the rain and snow producing processes under discussion, it may be interesting to speculate as to the probable value of aerial observations as a means of foreseeing the establishment of vertical temperature gradients sufficiently marked to produce precipitation in the form of rain or snow. These observations have shown that the diurnal range of temperature is practically eliminated at a height not greater than about 3,000 feet, and that under average conditions there is a decrease of temperature of about 1° for each 300 feet of elevation. They have also shown that at certain times and under certain conditions this temperature gradient is inverted, and that following a winter cold wave the air is warmed much more rapidly at a moderate elevation than near the earth's surface.

The establishment of the last fact is important in connection with a consideration of the snow producing process herein referred to. As snow, which closely follows a cold wave, is preceded by the appearance and evident formation of lofty cirrus, blending into cirro-stratus, clouds, it is probable that at such times the warm lower currents have a great depth; and while this warm lower body of air extends far beyond the extreme height at which observations have been taken, and presumably has a depth of at least four or five miles, it is quite probable that observations taken at an elevation of one or two miles would, under the conditions defined, show the rapid increase of temperature which precedes cloud formation and subsequent snow before the increase is indicated by surface observations.

During the summer months observations taken at these heights would unquestionably be of great value. In that season eye observations alone show that the rain-bearing clouds, which mark the limit of the warmer lower strata, have a very low altitude. Evidence of this is found in observations of thunderstorms and local rains whose occurrence is confined almost wholly to the warmer months. These storms commonly occur in the southern, and usually in the southeast quadrant of low barometer areas, and the low and rapidly moving scud clouds which forerun their breaking, and the cumulo-stratus clouds which frequently attend them, seem at times scarcely higher than the loftier trees and buildings; and the quick downrush of cold air, which is a feature of thunderstorms, is also a proof of the comparative shallowness of the lower warm strata during the period when summer storm conditions prevail.

It would appear, therefore, that observations taken at heights available with present appliances should yield valuable material for the investigator, and data calculated to supplement present skill in the art of weather forecasting.

TOPIC No. 7.—RELATIONS WITH THE PRESS, COMMERCIAL BODIES, AND SCIENTIFIC ORGANIZATIONS. HOW PROMOTED.

E. A. BEALS, Cleveland, Ohio, and A. F. SIMS, Albany, N. Y.

Mr. BEALS. I have long recognized the importance of the relationship existing between the Weather Bureau and the press, and I have given some thought as to how this relationship might be brought still closer to the mutual benefit of both parties. To voice my ideas into lucid and succinct statements, a rehearsal of a few well-known facts showing the motive governing the actions of both will not be out of place.

The Weather Bureau, in the first place, desires to utilize the press because of the unexcelled advantages it offers in the quick dissemination of weather reports issued for the benefit of the public, while the press, on the other hand, desires to publish these reports because they constitute news, and upon the quantity and quality of its news service depends the success of the newspaper. Thus is seen at once the strong inducement for cooperation existing between the two services. Wherever there is cooperation it is expected that benefits will accrue to a greater extent than would otherwise be the case.

The union existing between the Weather Bureau and the press, while it is not recognized as conveying a premium in dollars and cents, has underlying it the same incentive as would be the case in profit sharing; therefore, each of the services desires to use the other to advance its own interests. The publication of weather information then is excited by contrary motives, and it is to the interest of both parties, if the cooperation is to give perfect satisfaction, that they come as near together as possible in meeting each others wants. As an aid in this direction it is necessary that the situation be analyzed from both standpoints.

As I understand the newspaper side of the question, it is purely a commercial one. The success of the paper depending largely upon the quantity and exclusiveness of its news. Its employees are instructed to gather this news quickly, to obtain that which will interest the most people of all classes, and get "scoops," that is, to endeavor to get interesting news ahead of other papers. The more exciting, interesting, and exclusive it is the greater the merit and consequent reward to the agent collecting it. For this reason, newspaper men while anxious to get facts desire to arrange them so as to attract the most attention. The change of a comma in a sentence oftentimes alters its meaning very much. The emphasizing of a few words gives ideas considerably different from those intended, and an ingenious reporter, together with his colleague, the head line artist, does not find it difficult so to arrange an interview with the innocent weather man as to give him a very great start when he sees it in cold print. Thus, I have known the ordinary storm warning message containing the not very startling words, "Storm central over Manitoba, moving east; south winds will probably become high to-night and shift to west by Saturday morning; rain turning to snow Saturday," to be transposed in headlines something like this:

GREAT GUNS!

WIND WILL BLOW A GALE.

**CYCLONE, BLIZZARD, AND SNOW
PREDICTED.**

A notice of this character works a great injustice to the Weather Bureau, which desires its reports published without distortion or embellishment. Especially is this so in the case of ordinary weather stories given to the press from time to time. They, being of a scientific character, should be presented in a clear and unvarnished manner and devoid as far as practicable of all technicalities. The simplest language adequate to convey the desired information is far better than a complexity of scientific terms that only mystify the general public and thereby lessen the readableness of the article, in consequence of which its instructive or educative value is curtailed.

I believe that the occasions are numerous where officials fail to respond to the wants of the public, although having the material at hand for a very interesting story and the reporter right there to receive it. The reporter is rarely a scientific man, and seldom understands the workings of the Bureau sufficiently well to tell the story without your aid. You, not having the reportorial instinct for news, overlook the fact that there is anything to be made out of what you have, and thus the opportunity is lost. Our service loses, in this way, a chance to benefit or educate the public regarding some matter of note, and the newspaper has also failed to meet its wants in this respect. Both are anxious to serve, and the failure is almost, if not entirely, due to lack of a little care and judgment upon the part of the official in charge of the local weather office.

In my opinion there are a few officials in our service who go to extremes in furnishing weather items to the press. Then there are many who use excellent judgment, and take a great deal of pains in their treatment of this work. Quite a number, however, neglect it almost entirely, and when they do give out weather news bungle it most woefully.

What I wish to do is to call attention to some of these errors of omission as well as those of commission. First of all, I can not too strongly emphasize the benefits to be derived from sinking individuality, as much as possible, in weather stories. We should remember that the Weather Bureau, as a whole, demands our united efforts in its upbuilding. It is unnecessary to have our names accompany every article published; simply see that the credit for such matter is given to the Weather Bureau. My experience has been that an efficient officer's part in this connection will be duly recognized and credited, both by the public and by the Central Office.

In the baseball field team work is what counts; a club of star players without this quality will prove a losing club, while inferior players, with perfect team work, prove to be winners. The principle is the same in the Weather Bureau, and to make it of the greatest benefit individualism must be sunk.

I think the class of men who go to extremes in furnishing weather items to the press are without exception men who we may say are not highly educated; they rush into print so unwisely at times as to make the service appear ridiculous on account of the unlearned treatment they give the subject. These men, fortunately or otherwise, are generally the ones whose individualism is most prominent, and although the whole service suffers from their utterances, still it is not quite so bad as if their publications were wholly fathered by the Bureau. I can make no suggestions in the way of remedy for this evil, except, when it becomes too pronounced, to transfer such men to less responsible positions.

For the benefit of the class, before mentioned, who are neglectful, I will now try to state my idea of the way the publishing of weather news should be handled. First, we should make it a point to cultivate the esteem and friendship of the managing and city editors within our jurisdiction. This can be done by occasional friendly calls, generally made for the purpose of suggesting some improvement in the arrangement or in the character of the news regularly furnished. To make intelligent suggestions, the methods in vogue in other cities should be studied; then the wants of the community should receive consideration. These vary, of course, according as the locality is an agricultural, marine, or manufacturing center. Suggestions of this character will be cordially welcomed, and if the demands on space and expense are not too great they may be adopted.

Next, study the character of the reporters visiting your office. Make friends of them; show them that you are anxious to secure news to give them. If you can obtain anything in the news line wholly outside of your field, give it to them, or tell them where to get it. They will appreciate this interest on your part in their labors. Give them all the time you can possibly spare; they will not abuse it. I never knew of a reporter making a loafing place of a weather office. They are busy men themselves, and have other places to go when they have spare time on their hands. In your talks with reporters tell them how the service is being improved all along the line; tell them what you are doing yourself in that connection; tell them of instances occurring where weather information furnished individuals has proved of value; tell them of law cases in which the weather records have served useful purposes. Do not fail to show up all the good points that you can think of in favor of the service. I don't mean that these things should be published; when it comes to that, extreme caution must be used. These talks are to impress the reporter's mind with the importance of the work in your charge, as well as that of the whole Bureau. Not all newspaper men fully understand the scope of our work, but when one does he becomes a medium through which much good may be accomplished, whereas before he was a vehicle to be used with extreme caution.

Now, as to the news to be given out. You have a difficult task before you, for the reporter, perhaps, has only a "stickful" or two of space at his command and he wants to know "who, where, when, how, and why," regarding everything and he wants his information devoid of all technicalities. Elaborate treatises, perhaps, have been written upon a subject he expects you to fully inform him upon in a sentence or two. This, of course, can not be done, but you can always give him something interesting bearing upon the subject, and here is where your ability comes in play. Unusually hot, cold, or dry spells, heavy rainfalls, and winds all start the newspaper boys for your office. They want comparison at once, and if your records are properly kept you should be able to give them such information. If you can not, you have reflected discredit upon the service; the "oldest inhabitants" are immediately consulted to supply the deficiency, and thus the public mind receives further confirmation as to the changeableness of climate, the certainty of equinoctial gales, the infallibility of the goose bone and the ground hog in foretelling all sorts of calamities.

Another class of news to be furnished consists in seasonal occur-

rences, such as early and late frosts, first snows, when sleighing can reasonably be expected, annual floods, the opening and closing of navigation, etc. Every office should have these data tabulated, and, as the season approaches, give them out for publication. The public will be interested in knowing how this season compares with others, and the newspapers will be glad to be the medium of informing it.

Besides this class of news, there are many others constantly coming up at the various stations which can not be classified, but from which the alert weather man can, if he tries, make something that will be both interesting and instructive to the reading public.

We should ever bear in mind the powerful influence of the press for good or evil, and remember that each official is one of the cogwheels in this ponderous machine, as far as it concerns the welfare of the Weather Bureau. If we work smoothly with the rest of the machine, all is well, otherwise, not only is our lot an unenviable one but the whole service suffers in consequence.

I wish also to call attention to the fact that if a manufacturer or merchant has what he thinks is a good thing for the public, he spends thousands of dollars in advertising it. We, in the Weather Bureau, know that we have a good thing to offer, and we give it to the public without money or price. Under these circumstances, it is our duty to advertise our wares as frequently and as broadly as possible. There is no better medium by which to do this than the press, which is anxious to give us its aid as freely as we give the public our wares. Therefore, in closing, I will say that whenever these opportunities are neglected the service has failed in its duties to the public. The press, and through it, the public soon become dissatisfied and eventually the official so offending has to give way to another, without really understanding why his services received such scant recognition.

Professor ABBE. As editor I have a great deal to contend with in the way of sensational reports in the newspapers, and once or twice I have indulged in quite severe strictures on newspapers for making very sensational paragraphs out of quite ordinary meteorological phenomena. However, I do not suppose the Weather Bureau men are responsible for this. Lately, I noticed that one of our map distributors got his name in the paper as "Professor So-and-so," on the strength of having given quite an account of a case of ball lightning which was really not ball lightning at all.

Professor MOORE. In regard to this subject, it occurs to me that the Weather Bureau local official, in speaking for the public, can learn a great deal from the newspaper reporter. I have spent several years of my life in a newspaper office. I was not very successful as a newspaper reporter, and therefore they made a Weather Bureau official of me. Now, I find that if you tell a newspaper man a few facts, he will gather the central idea immediately, and enlarge upon it. You, in your technical report, will often lose sight of the most essential piece of news which the weather map contains and which

would be useful to the people. In Washington, as Professor Hazen knows, we have been endeavoring to write our reports in newsway language, and put forth officially such reports as the newspaper man would write if he had the technical knowledge we possess.

Mr. J. WARREN SMITH. I believe that the way for an official of the Bureau to promote the best relations with commercial and scientific organizations is to be a "man among men." That is to say, go among these organizations and take his place with them and fill it in every sense of the word.

If a man can not intelligently discuss the scientific and theoretical principles relating to his own profession scientific men have no time to spend with him. If an official of the Bureau can not meet commercial bodies, which are interested in the very matters that he is supposed to cover in his work, on their own ground; if while associating with farmers he does not appreciate the details of agricultural science and practice, then these individuals have no use for him, and no faith in the benefits that he is trying to "impose" upon them.

Would Professor Moore have had the success that he did while in Milwaukee or Chicago if he had stuck to his chair as if the bottom had been made of sealing wax? No, indeed. He went out among the people. He showed them that he was an expert and not a prophet; that the Bureau which he represented was for the very purpose of benefiting them, and that he was there, first, to find out what they wanted to know, and then to turn his efforts toward the successful foretelling of those particular features. In other words, he studied his customers, which is of just as much importance as studying your goods.

The day has gone by when it was all sufficient for a Weather Bureau official to sit on a high stool beside a long desk poring over papers covered with mysterious hieroglyphics, and look wise but say nothing when a man did venture into his sanctum sanctorum. The public is being educated faster than we are if we fail to keep in touch with the world and its ideas.

The only way that a business or a professional man can keep up with the times is to be continually on the alert. And in this age of rapid progress in all the arts and sciences, as well as in agriculture, transportation, and ordinary business affairs, we become antiquated unless by persistent and intelligent effort we keep abreast of the times.

Mr. J. Warren Smith offered the following resolution:

Resolved, That the Weather Bureau officials of the Department of Agriculture, in convention assembled at Omaha, Nebr., October 13, express their official appreciation of, and personal affection for, him whose executive ability and innate kindness of heart have done so much to extend the usefulness of the Weather Bureau and to raise the standard of its personnel. We extend greetings to the Hon. James Wilson, Secretary of Agriculture.

This was unanimously adopted by a rising vote, and the secretary was directed to send a copy of the resolution by telegraph to the Secretary of Agriculture.

Mr. Sims. The duty of primary importance is the placing before bodies representing the welfare of the people as much practical information as possible.

The best method of procedure in order to make plain to the many interests of our country the valuable work of the meteorologist is the common concern of the field workers of the Weather Bureau.

In order to bring about the fruition of our hopes we must go out in the highways and byways of commerce, agriculture, and science, and exact as tribute attention to the truth acquired by the pioneer investigators and zealous students who are blazing the way across the unexplored realm. We must lead the people out of the darkness of ignorance into the light of intelligent meteorology.

Great principles can not be stated in a few hours or understood in a few weeks; therefore, we must cultivate patience and persistence, and find strength in the knowledge and belief that purity of purpose, the common heritage of us all, combined with zealous effort and readiness to profit by the teachings of experience, seldom fails of its reward.

A detailed survey of the field of effort makes plain the fact that the special need of our time is meteorology made popular and practical and widely disseminated. To meet this need we must bring ourselves to the level of the plain people and impart to them in simple language a knowledge of the elementary principles of meteorology as found in the prefatory pages of the book of nature.

Any system of instruction must start by taking in the natural endowments, and must provide for their fullest development. We must awaken the imagination before we can successfully open the mind; this is the key which will unlock the students' inner nature. The well informed official can draw aside the curtain, see what is there, and sow the seeds of weather lore to take root and bear fruitage in the world.

There are certain lines on which the early meteorological training of commercial men must necessarily follow, courses distinct from those pursued by members of the professions; yet in some other respects both classes can pursue a parallel course, the only difference being that with the professional the process is slower, both in work and tangible results. We must apply to the business community, through its various organizations, the methods that have brought about a better understanding of our work on the part of the press.

The scope of the practical application of Weather Bureau reports will increase in proportion to our efforts and success in making them easily understood by the business men. The official should survey his field, district the business section of his city, arrange to make timely visits to the merchants especially interested in and benefited by weather reports, and get them in touch with the details of Weather Bureau work. As a general rule the active merchant can not conveniently devote, during business hours, the time necessary for that intensive study of weather publications which will help him in his work. As a general rule, theory neither attracts the business mind nor arrests its attention, and increased results follow only when mem-

bers of the staffs of the various boards and exchanges meet with the Weather Bureau officials for the mutual exchange of ideas and suggestions designed to increase the practical application of weather reports. Staff officers of the boards and exchanges having the field of effort and its condition constantly before the mind's eye are thoroughly competent to answer intelligently questions regarding weather, crops, and prices.

We act in the capacity of purveyors of facts and generalizations regarding the weather in shape best suited to the various business interests. The staff officer in charge of the bureau of information can furnish members facts and figures; the application of the data is the concern of the member.

The official charged with the duty of issuing daily synopses of the weather should keep in mind the interests best served with weather reports and incorporate in his writings such timely facts as will best serve particular interests during critical periods.

To the assistants on stations located in our large cities should be delegated the work of keeping thoroughly posted on grain, cotton, etc. They should cultivate the acquaintance of the man in charge of the exchange desk of a great daily paper and secure all exchanges containing interesting items regarding the weather. They should seek to induce elevator companies and extensive grain dealers to give copies of the daily rainfall information received by them from correspondents located in the principal wheat, corn, and cotton belts. The superintendent of telegraph of the granger railroads should be requested to secure from train dispatchers along the line of their roads, at the time of test, reports of rainfall or damage by storm. Probably this could be considered as railroad business, and not in violation of the contract by which a railroad leases wires from a telegraph company for the transaction of railroad business. The principal wheat, corn, and cotton areas should be plotted on a chart by townships, together with the percentage of yield as given by the United States Department of Agriculture, the acreage on which the percentage is based, and the daily rainfall.

A synopsis of the rainfall, together with interesting information regarding the effect of weather on crops, should be printed on the back of the chart. To be plain, we should have our wheat man, our corn man, our cotton man, on each large station keep thoroughly posted on specialties from seedtime to harvest, and write his line in a popular style and publish a daily synopsis, especially during critical periods. Each popular bulletin should give the situation up to date and be progressive; the latest bulletin should contain a statement of the salient features of the preceding sheets. This system is calculated to serve as a herald of the great weekly crop bulletin now issued from the Central Office.

Many business men of to-day have not had the benefit of even the least personal study of meteorology, and I know of no better method of lifting them to a normal meteorological plane than that of giving, during the winter evenings, when "smokers" and "kommers" are in order, short talks on the practical use of weather reports, and imparting to them in a simple way the gist of the information that is contained in the chapters on meteorology printed in the standard physical geographies for the benefit of our future commercial men. As a general rule, many leave school and enter upon a business career with a

bare modicum of knowledge of the higher branches of study. For that class the chapter on meteorology has especial value.

The daily weather map is the one publication around which the structure of our Bureau is being erected. The business men of to-day require an early service, and that demand will be satisfied if the official will glean the most salient features of the daily map and present them to the business men in the form of an attractive bulletin. Pictures and drawings please the popular fancy, for the reason that they require a minimum of effort to comprehend. They are intelligible to the mind insufficiently tutored to intelligently conclude from a column of figures. A picture of the weather and temperature flags to the right of the wording of the daily forecast, the Washington forecast, in red; the cold wave, information, or other signal, to the right of the wording of the warning message received from the Central Office, in blue; the synopsis of the weather report, in black; in short, all the information that an official has at his disposal can be sent out in a simple and attractive form one hour earlier than the weather map.

The Monthly Weather Review commands respect and admiration, but it is unknown to the plain people, for the reason that it does not appeal to them in a popular form. All interests would be well subserved by maintaining the present high standard of the Review, while also adding elementary lessons tending to explain the alpha and omega of the aerial ocean. The Weather Bureau kite could be used as a vehicle for these popular trips through the atmosphere and affords a popular way to treat storms of the month.

Normal colleges are well fitted to materially aid in the mission of educating the public in meteorology, for the reason that many of their graduates enter the ranks of teachers. A little effort and tact on the part of the official will result in preparing such students, so that when they enter the ranks as teachers they will be thoroughly competent to explain in simple language the weather maps and cards posted in the class rooms.

At teachers' institutes, such as are held every year in the Empire State, the secretary can arrange to have papers on meteorology in its relation to school work read and discussed, and, with them, short talks on how to use weather reports will be productive of much good.

Many fortunate young men of our cities, towns, and hamlets are temporarily absent from the home fireside while attending college. As a general rule, they arrange to spend the vacation season at home. At that time it may be easy for the official to interest a young college man in the *modus operandi* of a station of observation. In one case, at least, such effort has led to the organization of a science club at college and the acceptance of questions in meteorology as subjects for debate.

Such work is well calculated not only to interest the parent in our service, but tends to cause the student to study, not with the mere object of attaining high marks in the class room, but the further object of turning such study to practical account after he enters the business world to achieve his own fortune.

Even the kindergarten presents a field in which one can make primitive meteorology the favorite nature study. The official can cooperate with the teacher by furnishing drawings of a cloud form, a thermometer, a barometer, a wind vane, a rain gauge, etc. One child can cut while another can paste the pieces together. In this connection I

would suggest that this matter be brought to the attention of the National Educational Association, with a view to having the work herein outlined introduced in the schools of our land.

It might be of interest to you to know that our maps are eagerly scanned by the pupils in the Institution for the Instruction of the Deaf and Dumb. The supervisor of that institution was instructed in our methods, and now some of his boys are well advanced in elementary work.

Some time ago a gentleman called at the Albany office of the Weather Bureau and stated that the young men at the General Electric Works were so interested in the weather map that he was obliged to remove it from his office room to the hall. When we consider that these student engineers come from all quarters of the globe, such a report is, to say the least, most gratifying.

An interest in meteorology can be stimulated by the incorporation in the regents' examination papers of questions relative to the elements of this subject.

Secular schools offer a wide field for legitimate effort, but not the only field, as you will learn through the following incident: Not long ago it was my good fortune to casually meet the pastor of a church to whose care is confided the management of the House of Shelter. While homeward bound the conversation flitted from one subject to another, and finally rested on the topic of the weather and the forecast made by the Weather Bureau for the great floral parade held at Saratoga, N. Y. The conversation brought out the fact that the clergyman was inclined to the belief that the study of meteorology tended to make man agnostic. He also stated that it gave me employment, and thereby operated in the direction of doing good. I pleaded in bar trial to the first specification, and guilty to the second. I told my friend I was glad to learn where he stood, for the simple reason that it afforded me an opportunity to labor in a rich, uncultivated field, and sow acquired truth. I stated my belief that agnosticism was not favored by scientific pursuits, and assured him that the study of meteorology brought the creature, man, nearer the Creator. I pointed out to him a line on which Sunday school teaching could be made interesting. Observation teaches us that the comparative and inquisitive mind finds difficulty in harmonizing the doctrine of the three persons as one and the same (The Trinity); it very often proves a stumbling block unless we seek its counterpart in nature, e. g., hail, rain, snow, the three totally different in appearance, yet when subjected to heat the same—water. I stated that meteorology had lifted the veil for me, and while I could reason in the abstract, to my own satisfaction, at least, as to whence we came and whither we are drifting, I could not conceive of a beginning for the Creator himself; however, in the light of past events, and in view of the fact that meteorology had solved many perplexing problems for me, I looked forward to a future replete with bright promise. I assured him that I would not advocate the substitution of philosophy for religion, or unduly cultivate the abstract reason as the basis of the former, and ignore the superhuman as the condition of the latter. Admitting that all projects fail when they do not tend to cultivate the spiritual sense which reveals God, we should teach that moral freedom is the chief end of man, and that among other methods meteorology can also be used as a means to that end. My friend in

parting urged me to think of more illustrations for him. This comes under the head of special privilege, for the reason that it is the best method of promoting the interests of meteorology, and tends to converge all paths to the brotherhood of man and the Fatherhood of God.

When requests for maps are received from teachers and others interested in our work it would be well to state in reply that the Weather Bureau extends the courtesies of the office, and that the official in charge would be pleased to have the teacher, scholars, and others call when they next visit the city, and learn the *modus operandi* of a station of observation. Such an invitation will invariably be looked upon as special; it will be far more effective than the general invitation printed in our publications.

We should seek opportunities and get in touch with agricultural associations for the purpose of devising ways and means for obtaining and furnishing the data best suited to show the importance of local climate upon plant life. We help to place the American farmer above competition by enabling him to make the most of his acres through the selection of plants best adapted to his soil and climate.

In all cities the problem of the water supply is becoming more perplexing. We should consult the engineering association and other scientific organizations, learn of their needs in our line, and set about to furnish the data.

The medical associations and sanitary architects of to-day are not at all decided as to the lines on which our work, so far as relates to them, should be laid down. We must take the initiative. To the casual observer it appears likely that in the study of atmospheric pressure during the season when the ground is frozen may be found the true solution of a problem involving sanitary architecture.

As is well known there is an afflicted element in our population who are always seeking to restore health, prolong life, or ward off threatened disease. For them and the guardians of the public health a publication, giving a classification of climates best adapted to combat diseases in their various stages, would be valuable and would fill a public want. The publication should give the location of all sanitariums, the elevations, and local climatology, also the routes by States and seasons over which patients can best travel. With such a publication at hand the physician could map out a trip with a view solely to the patients welfare, and not leave the matter to a ticket agent who is trammled by the consideration of commissions, etc. In every community one can find some old mechanic whose associates and surroundings are of a thoroughly bohemian character. The arguments, and all incident thereto, given and taken over the work bench possess a value and often prove far reaching in their results; such men may be found to be competent to discuss subjects in elementary meteorology and devise apparatus and mechanisms.

One could go on *ad infinitum* pointing out where it is possible to open up new lines of activity. Experience teaches that as to meteorology it is much easier to instruct the young than to convince the old. We need to labor all the more diligently with those who have attained maturity, for it is among the older members of a community that we find a proneness to criticise unjustly and unfavorably that which they do not understand. Our efforts to spread the truth will lift us above our own intellectual horizons and give us glimpses of the light beyond.

In conclusion, it may be stated that absolutely correct weather forecasts would bring about universal peace of mind, prosperity, happiness, and all that is truly good. How to gain a comprehensive knowledge of the surgings, tossings, and pulsations of the aerial ocean has occupied my leisure moments ever since I began to study the serious side of our work, and while I have perceived many objections, surmounted many obstacles, and eliminated many faults in my plan designed to better our instrumental equipment, I am loath to explain it now, for the reason that, while I firmly believe it will prove to be practical, I am not thoroughly satisfied with it, and to a casual observer it will appear frivolous and only worthy of a place among iridescent dreams. However, be that as it may, the mechanism I have in mind is intended to make a continuous record on a movable board, so that an official can step into the instrument room at any moment and get a kaleidoscopic view of the bends and changes in the isobaric and isothermal lines and their history for the day.* The Central Office register or map maker is to have a number of coils, two for each reporting station, each pair of which acts as automatic cut-outs and completes the circuit through the up or down pen of its own station, and thereby induce in the Central Office arm the motion of the corresponding station arm. The synchronizing circuit of the central Washington clock is to be used for this automatic work. The system herein outlined could be best perfected by experimental work in the Central Office laboratory where a number of barographs and thermographs could be subjected to variable pressure and temperature and cut in on an improvised circuit. The considerations entering into the question of the adoption of the plan outlined are cost and value. It may be stated that this method provides for a minimum of telegraph service—the man on guard would send out warnings of no uncertain value, and only in the direction in which warnings are needed. The data secured would in all probability advance the standard of meteorology far beyond the hopes of the mortal of to-day. It would revolutionize and simplify our service, and bring to the perception of finite man that which is now infinitely beyond his ken.

In this connection I respectfully suggest that a sketch plan and specifications of the proposed system be made and submitted to our station men for study, suggestion, and remark. Make it, as it were, a contribution to meteorology from America. After all the testimony is in, the Central Office staff can classify all suggestions and remarks of apparent value and evolve the best mechanism to bring about the fruition of our hopes.

Professor ABBE. I have always been curious to know how many of our men have actually done something toward getting meteorology taught in schools. How many of you have had a chance to talk to schools, or colleges, or universities, or to teachers, in any way? Please rise.

(Nearly everybody present rose.)

*A spider web with its occupant crossing the radial lines does not look unlike the chart the mechanism would make. Meridians and parallels stand for lines in web, and storm areas crossing plots take place of spider.—A. F. S.

Mr. T. B. JENNINGS. I would like to go a little further. The school is not the only place where you can teach. I find the Epworth League, and organizations of that kind, very anxious to receive this information. At Topeka we have a number of organizations of that character, and they give me very frequent calls. I have to make regular visits to the city schools and the schools near the town, but in addition to that there are Epworth League and other organizations of a literary nature in the town. You can create an interest in the subject of meteorology by bringing it to the attention of these meetings.

TOPIC No. 8.—METEOROLOGICAL STATISTICS: HOW TO IMPROVE THEM THAT THEY MAY MEET THE NEEDS OF THE MEDICAL PROFESSION, HYDRAULIC AND SANITARY ENGINEERS, PROMOTERS OF IRRIGATION PROJECTS, ETC., AND DOES THE PRESENT MONTHLY SECTION REPORT MEET SUCH NEEDS?

E. W. McGANN, New Brunswick, N. J., and W. M. Wilson, Milwaukee, Wis.

Mr. McGANN. Owing to the very limited time at my disposal, I find it impossible for me to enter into a lengthy discussion of the subject, "Meteorological statistics: How to improve them that they may meet the needs of the medical profession, hydraulic and sanitary engineers, promoters of irrigation projects, etc." In New Jersey the meteorological data already collected, tabulated, and published from time to time, have been of incalculable value to the several professions named.

As far back as 1886, the late Prof. George H. Cook, Director of the New Jersey Weather Service, said that the objects of the service would be to observe and utilize every feature of the weather that affects the prosperity of the citizens of our State as to crops, health, life, etc.; that it would give to every county a government standard of temperature and rainfall; that it would put within the reach of local agricultural societies means of accurate observation which in course of time must be valuable to any locality in the study and adaptation of cereals; that it would lead to the collection of rainfall data over the different watersheds of the State of New Jersey which supply the waterworks of our large cities; that it would call attention to our winter and summer resorts as to their desirability as residences and to a better practice of medicine, when the physicians throughout the State could study disease with reliable and accurate data by their side; that it would give valuable aid to engineers, in the study of the rise and flow of the various streams, and also furnish invaluable information in the study of irrigation. Now to prove that we have done all this, I respectfully refer you to the subjoined letters from celebrated engineers and professors of our State experiment station, as to the practical value of the work already performed by the New Jersey section:

NEW JERSEY AGRICULTURAL COLLEGE EXPERIMENT STATION,
New Brunswick, N. J., October 5, 1898.

DEAR MR. McGANN: Concerning the weather reports and crop bulletins issued from your office, I find both of them, in different ways, to be of great importance to me. The development of insects is influenced to a very large extent by the weather, and sometimes by the weather during a very brief period.

This has been known in a general way for a long time; but heretofore we had only a vague conviction that a season was wet or dry. Since I have had your reports for constant and ready reference I have been able to certainly connect the unusual abundance of certain species with certain weather phenomena. Thus, I have been able to warn melon growers in our State that whenever there was constant warm, pleasant weather, with moderate rainfall, between June 15 and July 10, they might expect serious injury from the melon-plant louse; but whenever, between those dates, there occurs a heavy or cold storm, little or no injury is to be anticipated. This one fact, definitely established, is of great money value to our vine truck growers, since it enables them to either prepare for fighting the insects or for substitute crops, in case they prefer not to do so.

Other cases might be cited of equal importance, but this is enough as an instance of why I consider the reports of such great service to me.

The crop bulletin, with the service so well established throughout the State, gives a weekly picture of the conditions as they appear to the farmer, and enables me in many cases to note the appearance of an unusual or threatening pest, while in all cases I have at the end of the season an account of all the notable insect occurrences of the season.

The service, from this one standpoint alone, is abundantly worth all that it costs.

Very truly yours,

JOHN B. SMITH.

NEW YORK, October 4, 1898.

Mr. E. W. McGANN,

Director, New Jersey Weather Bureau, New Brunswick, N. J.:

DEAR SIR: During the period from 1890 to 1894 I was engaged in investigating the capacity of the streams of New Jersey to furnish water for public water supply or for water power. In connection with that investigation I gauged a number of streams in the State, and obtained from you contemporaneous rainfall measurements upon the several watersheds. The purpose of my investigation was largely to determine the relation between the run-off and the rainfall, and to trace the storage of rainfall in the subsoil and its later delivery to the stream during periods of light rainfall. In connection with this work your rainfall statistics were of the greatest value. If you had not been in position to furnish them, the expense of my investigations would have been greatly increased, and to such an extent that their practicability would have been threatened. In connection with this and other investigations, I have used your records continuously since the inception of your work, and they have proved to be of great value.

My practice in New England and the Middle States being mainly in the line of water supply and water power has made me so dependent upon the work of our Weather Bureau that I can scarcely conceive of the possibility of going back to the conditions of some years ago. It yearly becomes necessary to estimate more accurately the amount of precipitation, evaporation, percolation, and run-off of our several stream basins. Indeed there are many questions still to be solved in this connection, and the results of such a thorough study of the subject as is made possible by such full records as you have kept in New Jersey will undoubtedly add largely to our knowledge of the laws and conditions which affect the yield of streams, the height of the water table in the ground, the amount of evaporation, etc. These problems are important to the hydraulic engineer, the sanitarian, and the scientific farmer or horticulturist. It is especially advantageous to have the stations close together, as you have them in New Jersey, where they are so distributed as to properly represent the different types of topography and varying exposures to the storm winds.

I have long been of the opinion that the best way to determine the relative amount of evaporation from forested, cultivated, or barren country is to carefully measure the rainfall for such areas and at the same time the amount of water running off in the streams. Such observations over a number of well-selected watersheds must give more accurate information than any experiments on a more limited scale. The planning of the important and costly works needed to supply water to our cities, to dispose of their sewage, to produce water power for electric transmission, etc., requires accurate knowledge as to the yielding capacity of our streams, the ultimate source of which is, of course, the rainfall. Furthermore, I have long been of the opinion that there is a fairly well-defined connection between the prevalence of certain diseases and the rise and fall of the water in the ground. I will note in this connection, however, that the rise and fall

of this ground water is not always, as has sometimes been supposed, exactly contemporaneous with the occurrence of heavy or light rainfall.

But the engineer or sanitarian is also concerned with the temperature, which increases or decreases the amount of evaporation. He is likewise interested in the wind movement and position of the barometer. In fact, he needs daily the fullest possible record of the weather conditions in his district. I can not fully express my appreciation of the value to me of such records as you are making in New Jersey.

Yours truly,

C. C. VERMEULE.

Prof. B. D. Halsted of the New Jersey State Experiment Station, New Brunswick, states as follows:

The meteorological data compiled by the Weather Service are of great value to me in my work in many ways.

1st. By means of the weekly crop bulletin I am informed of the condition of the various crops as concerns their fungous diseases.

2d. The bulletin gives an opportunity for informing the crop growers upon the nature of certain outbreaks of rust or blight, with remedies for the same.

3d. The monthly record of the weather is of special importance to me in my work with plant diseases.

4th. The annual reports are most of all important, as a record of meteorological facts from which generalization may be drawn of great value to crop growers.

The following statement is by Director E. B. Voorhees, of the New Jersey State Experiment Station:

The New Jersey Experiment Station has for the past four years been making a study of the need of irrigation in the State, and in this work the records of the Weather Service, both in reference to the rainfall and temperatures, have been of inestimable service. From these data we are able, not only to determine the deficiency in rainfall from the standpoint of actual supply of water to plants from that source, but also the influence upon the flow of streams from which irrigation waters may be derived. Thus, a careful study of this matter has indicated, not only the direct need of additional water, but the areas that are capable of being brought under water by means of ditches and canals. It has been shown that even in the driest year which has been experienced, and in which the need of water is very great, the supply from streams is sufficient to irrigate 325,000 acres, which, if properly managed, and at a reasonable cost, would increase the value of the agricultural products at least 30 per cent. As before stated, the data upon which this conclusion is based could not have been derived without the careful records of rainfall and temperature.

Mr. WILSON. By arrangement between my colleague and myself, it has been agreed that my remarks should be confined principally to climatic statistics as applied to what may be termed medical meteorology. There can be no question as to the intimate relation existing between climatic conditions and the production and the cure of disease, and the truth of this statement has been most forcefully illustrated by the experience of our troops in the recent Cuban and Puerto Rican campaigns.

The origin of diseases which are produced or propagated by certain conditions of temperature, moisture, and wind can be studied only in the light of a complete and comprehensive knowledge of the meteorological conditions which go to make up the climate where such diseases are found, and manifestly it is one of the important duties of the Weather Bureau to furnish this information in proper statistical form for such investigations.

Two questions immediately present themselves: 1st. What particular meteorological statistics are needed by the medical profession in order to enter upon an investigation of the origin and prevention of those diseases known to be largely dependent upon the influence of

climate? 2d. Does the present form of statistical information meet the requirements in this connection? It is a well-established fact that the propagation of the germs of disease, so far as the natural conditions of climate are concerned, depends mainly upon the proper degree of temperature and a sufficiency of moisture, but the exact degree of temperature which is most favorable for their development and growth or that under which their destruction is most readily accomplished must be determined for each special group by experimental investigation. To illustrate: The germs of yellow fever are destroyed or, at least, rendered latent by a freezing temperature, while those of typhoid fever and smallpox resist almost any ordinary degree of heat or cold. It has been only of comparatively recent date that the so-called "germ theory" has taken firm hold upon the medical profession, and there are still many eminent physicians who are sceptical as to the truth or value of the theory, and argue, with much show of reason, that climatic conditions have more to do with decreasing the power of the human organism to resist disease than in vitalizing the germs to the point of aggressive activity. The truth probably lies between the two extremes, but the difficulties to be encountered in an investigation of this character render a speedy solution of the problem extremely improbable. In either case, however, climatology is the important factor, and it can scarcely be said to be the province of the Bureau to settle the biological question.

During recent years there has been some work attempted and something accomplished in the field of medical meteorology, but what has been done can scarcely be called even a beginning. The ground has not yet been marked out, nor the lines upon which the investigation should proceed established. The work thus far accomplished has been often done by those not actively engaged in the practice of the profession, and oftentimes with but little support or encouragement. Indeed the average practitioner has little time and scarcely any opportunity for original research, especially on a line requiring a specialized knowledge of both medicine and meteorology.

His energies are directed to subjects, which if less difficult, are to his mind more practical, and give greater promise of immediate returns, and for future progress in this direction we must still look to those who are without the active ranks of the profession.

In regard to the form in which meteorological statistics should be prepared for the use of the medical profession, it would seem that there is greater need of an active effort to increase the interest of the rank and file of the profession in the work already done, and to secure their cooperation for the future, than of any elaborate change in the present methods of publication of our climatological statistics.

With the lengthening of the term of study to four years, which has been adopted by most medical colleges, it would seem that short courses in the elements of meteorology, with special attention to sanitary climatology and engineering could profitably be introduced into the curriculum of every medical school. This would at least give the practitioner a working knowledge of meteorology in its relations to medicine and sanitation, and render the work along these lines more certain of appreciation. Until this elementary work is accomplished, any effort in the direction of medical meteorology will be largely devoid of practical results. From my observation and experience I am confident that meteorology is fully abreast of

medicine so far as each science relates to the other, and I am constrained to the opinion that under present conditions any radical change in the form of the statistical information compiled by this Bureau could not be profitably introduced.

Professor HAZEN. I was much interested in Mr. Wilson's remarks as to the proper form of meteorological statistics for the benefit of physicians. Whenever there has been a medical congress in Washington I have taken pains to ask just exactly what physicians want in the line of statistics. They are not agreed. Some want the relative humidity, others the temperature; and as near as I can make out, aside from those referred to by Mr. Wilson in regard to the effect of heat and moisture upon germs in such a climate as Cuba, physicians are not agreed as to what they want. We may well wait until they are agreed. I think Dr. Baker, of Lansing, Mich., is the only physician who has devoted special attention to this subject of medical climatology; and all his work, I think, is in regard to seasonal effects. At present, therefore, the medical world is certainly at a loss in regard to what it wishes from the meteorological standpoint.

Mr. CLINE. There are a great many physicians who have never studied meteorological statistics, and many of them know nothing about handling meteorological instruments, because when they were studying medicine, meteorology was not taught, and in a great many schools it is not taught to-day. Before we can get any class of men to agree as to what they want in any line of statistics, we must first instruct them as to how we get those statistics. Now, in Texas I don't believe they teach meteorology in any practical way in the university, but in the medical department they have a graduate course of lectures which is given to the third and fourth year men. This course of lectures is required of every candidate for graduation; they must pass an examination in it, and it counts for 20 per cent in pathology. I think it would be a good idea to get the universities to add a course of meteorology, theoretical and practical, to the curriculum of their medical schools.

Professor HAZEN. Taking the question of consumption, for example, you will find almost every physician says you must have a dry climate for that disease. Yet physicians say Madeira is one of the best places for consumptives, though Madeira has one of the dampest climates.

Professor ABBE. This topic may justify me in saying one word about the subjective temperature. We can individually make a small contribution to this subject. I think the simplest way is this: When you think "This is a lovely day," make a note of it. It may exhilarate you, or it may quiet you, but anyhow make a note of the fact

that with this wind, this temperature, and with this moisture, you feel first rate. Keep this little record for a year, and when you get through you will see what a great variety of atmospheric conditions you have experienced and yet felt magnificently every time. Do not let this seem like a *reductio ad absurdum*, but send these data to me and I will put them in a little chart that will illustrate the subject very instructively. The horizontal line will be for relative humidity, the vertical line for temperature. The figures for wind velocity will be written at the proper point to indicate that one feels first-rate at that temperature, humidity, and wind. Eventually we draw a line of perfect comfort; and this line differs wonderfully through the year, as we adapt ourselves to the seasons.

TOPIC No. 9.—PAPER: SOME NOTES ON AGRICULTURAL METEOROLOGY, WITH SPECIAL REFERENCE TO THE RAINFALL ELEMENT.

CHARLES E. LINNEY, Chicago, Ill.

Mr. LINNEY. The great fund of climatological information and the weekly and monthly bulletins of the Weather Bureau serve not only to show the effect of untoward weather conditions upon growing crops and the conditions under which they thrive or perish, but also represent the agricultural possibilities of each State, and the many other problems of interest and value connected with the general science of meteorology and climatology within the United States. The field covered is large indeed, and one can not hope to do more in a limited paper than to touch lightly upon a small portion of it. I wish, however, to delve into a few of the more common things in agricultural meteorology, with special reference to the rainfall element.

The rainfall element may properly be considered as first in agricultural meteorology, since upon the moisture, next to the temperature if not in advance of it, a country becomes fertile or barren. It is true that moisture can be artificially supplied if bountiful Nature fail, but even to attain this end knowledge should be had of the desired amount of moisture and the time when it should be supplied, not to mention also, the soil, the crop, the season, and other conditions that combine to make a country either fertile and bountiful or barren and sterile.

It is said (Year Book, 1894, p. 156) that in the humid portions of the United States, having a mean annual rainfall of about 40 inches, 50 per cent flows off into the streams, and is of no direct benefit to agriculture. This excess of rainfall reaches the streams partly by flowing over the surface of the ground and partly by slow percolation through the soil, and thus only 50 per cent of the rainfall, or 20 inches annually, evaporates directly from the surface of the soil or is transpired by plants. Therefore, there are about 20 inches of rainfall at the disposal of the agriculturist, and the highest art of cultivation consists in conserving this moisture, reducing that lost by evaporation from the surface of the soil to a minimum, and maintaining a sufficient amount at all times for the use of crops. The figures given by Mr.

Frank Leverett, in his pamphlet on the Water Resources of Illinois, (p. 40), cause him to conclude that in this State the annual run-off is only about 21 per cent of the rainfall. The rainfall being about 38 inches, the estimated run-off is about 8 inches.

Mr. F. H. Newell, in the Fourteenth Annual Report, United States Geological Survey (Part II, pp. 95-155), estimates that the mean discharge of rivers of small size in the eastern part of the United States is about two to three times that of Mr. Leverett's estimate for Illinois. This is due to the fact that in the eastern district the discharge is accelerated greatly by the steeper slopes, and also by the greater annual rainfall, which accounts for the greater percentage of run-off.

Mr. Newell, in a diagram representing the relation of the run-off to rainfall, has indicated that for an open country, with low slopes, where the annual rainfall is 40 inches, a run-off of 15 inches may be expected, while with a rainfall of 30 inches a run-off of about 8 inches is likely to occur, and where the rainfall is 20 inches only about 3 inches reaches the streams, the quantity rapidly decreasing with less rainfall.

It will thus be seen that the current variations in the estimates of the run-off can be nearly equalized when one takes into consideration the slopes, the soil, the annual rainfall, etc., and that finally if the rainfall is about 20 inches annually, most of it will be needed to produce a crop.

The rainfall normals given in the report of the Chief of the Weather Bureau (1891-92, p. 444-445) show that for the season from March 1 to October 1 about 15 inches of rainfall may be expected at Bismarck, N. Dak.; 16 inches at North Platte, Nebr.; 17 inches at Dodge, Kans.; 19 inches at Port Huron, Mich.; 20 inches at Green Bay, Wis.; 21 inches at St. Paul, Minn.; 23 inches at Chicago, Ill., and Pittsburg, Pa.; 24 inches at Columbus, Ohio, and St. Louis, Mo.; 25 inches at Des Moines, Iowa, and Cairo, Ill.; 27 inches at Indianapolis, Ind., Kansas City, Mo., and Fort Smith, Ark.; and 30 inches at Nashville, Tenn., with slight increase toward the east and south, and marked decrease as we go west and north.

While our rainfall records are of great value, they give little more than the past conditions and the average conditions. Even the record of daily rainfall is more or less unsatisfactory, as it can never take into consideration the rate of fall or the condition of the soil at the time, or the locality of the rainfall. In regard to these points it is said (Year Book, 1894, p. 156):

There is one factor which has a very important bearing upon the conditions in the humid as compared with those in the arid region. In the humid region of the Eastern States the soil is continuously moist from the surface down to a depth at which it is completely saturated, and from which water is constantly flowing out into wells, streams, and rivers. The water descends through the soil both by virtue of its own weight and by capillary force. According to capillary laws the water is pulled downward when the subsoil contains less water than the soil. Gravity and capillary force are both more effective in moving water through a moist subsoil than a dry one; hence there is danger in the East of water being pulled down below the reach of plants in time of drought, while in the West, where the subsoil at a depth of a few feet is continuously dry, this could not happen.

An inch of rainfall coming gently on a soil in fit condition to absorb it may prove of greater value to a growing crop than several

inches coming in a downpour on a saturated soil; the one, in fact, may be the life of the crop, the other its death by drowning, for drowning is quite as ruinous to a crop as drought. A crop season may be a highly successful one on a minimum amount of rainfall if this comes at the proper intervals and in proper amounts; it is usually a deficient rainfall rather than excess, which is the ruination of crops year after year; the deficiency generally prevails over limited areas, but often over such a large area of country that the prosperity of the agricultural community is seriously impaired, and many an individual farmer is ruined.

Practical farmers have repeatedly said that excess either of moisture or dryness is fatal to good crop growth, and yet so general a statement means little, for this general average, which is so desirable, can only be determined by the slow process of daily, monthly, and yearly observations covering a considerable period of time, and once it has been determined there is no certainty that the farmer may expect it, or that the seasons will not run by extremes.

How indefinite and uncertain this "average" condition is has been in part discussed in my first view of what is absolutely necessary to produce a crop, but it can be more clearly shown by a consideration of the amount of moisture which will produce a maximum crop, or impart to a plant its most vigorous growth and sustain it throughout the crop season. Prof. F. H. King, Director of the Experiment Station of the University of Wisconsin, has carried on an elaborate series of irrigation experiments to elucidate the question, "How important is soil moisture, and how much do our soils require for maximum productiveness?" In his annual report for 1896, p. 189, he gives the results of his experiments for that year, and compares and contrasts them with those of 1894 and 1895, the two preceding years of drought.

From his experiments it appears that during the season of 1896 not only was the rainfall fair in amount, but it was generally well distributed, and that being true, the irrigation experiments afforded an excellent means for determining, under field conditions, how much moisture is really needed in the soil to insure maximum yields.

In one table Professor King gives the seasonal rainfall from the 1st of May to the 31st of August for the three seasons. This period is three months shorter than that I have considered in quoting rainfall heretofore. But from his table it appears that not only was the total rainfall for 1896 much larger than that of the other two years, but there were only two 10-day periods when the precipitation did not exceed half an inch and but one where it did not exceed 0.3 of an inch. On the other hand, during 1894 there were six 10-day periods and in 1895 seven of less than half an inch of rainfall, and four periods in 1894 and six in 1895 when the rainfall was less than 0.3 of an inch.

During these three years corn was grown on the same piece of ground, and the mean yields of dry matter per acre may properly be used as an index of the influence which the varying amounts and distribution of rain had upon the crop yields. The total rainfall and the yields were as follows:

In 1894 a rainfall of 9.72 inches gave 6,674 pounds.
 In 1895 a rainfall of 5.82 inches gave 2,768 pounds.
 In 1896 a rainfall of 15.20 inches gave 7,995 pounds.

In the soil problems for 1896 clover, rape, corn, potatoes, cabbage, mangel-wurzels, and turnips were experimented on, and all except the clover were grown on soils in alternating strips of irrigated and non-irrigated land. The results with the potatoes show that, although slightly more than 15 inches of rain fell during the crop season, still five timely applications of water, amounting to 10 inches, increased the yield nearly 100 bushels per acre. With the corn, in all cases where it was possible to obtain checks, the irrigated land produced about a ton per acre more water-free dry matter than the land not irrigated; and the same general result was had with the cabbage. The cost of the irrigation was more than paid for by the increased crop yield. From which Professor King summarized the results as follows:

The great lesson to be learned from these results is that we must have an abundance of water in order that our crops may avail themselves of the plant food stored in our soils; not that water is everything, but the fertility of the soil counts for naught without it.

These results of Professor King also show that the greatest yields were had when the rainfall and irrigation equaled about 27 inches, although the greatest gain was had when the small rainfall of 1895 was brought up to more than 31 inches by the addition of 26 inches of water, resulting in a gain of more than 200 per cent in crop yield. It would thus appear that maximum yields are to be secured with 25 to 30 inches of rainfall properly distributed during the crop season, and that with this amount of water, sunshine and temperature also being favorable, the plant has as much moisture as it requires to give its fullest energy and largest crop yield, while if more be added puddling of the soil, baking, stunted growth or drowning would result.

Where irrigation is not possible subsoiling is a very desirable feature. The effect of subsoiling upon the ground is to increase the water capacity of the soil stirred; decrease the capillary conducting capacity of the soil stirred; increase the percolation, or gravity capacity of the soil stirred for water; increase the percentage of water retained in the subsoiled ground which is available for crops; increase the chance for root development of the plant at a lower level in the subsoiled land, by admitting air and moisture; and, finally, to make available a very much larger field for plant food.

Careful observation and analysis of the waters of the sea show that the plant food lost in cultivation of the soil by leaching is exceedingly small. The sea secures mostly those alkaloids which are not needful to plant growth. The rock ingredients which are leached out in the largest amounts are those of which the smallest quantities only are required by most plants, while, of those ingredients which are specially needful to plant nutrition, only potash is removed in appreciable amounts by the weathering of the soils from excessive rainfall. On the other hand, insufficient rainfall is almost always shown by the appearance upon the surface of the land of an efflorescence of alkali salts, which characterizes the well known alkali land. And yet these arid or semiarid lands are largely composed of disintegrated limestone, or are lime lands, and are wonderfully rich and fertile, and need only irrigation and the conserving of their rainfall to make them exceptionally productive.

These facts all point to a number of conclusions: First, few of the central valleys north of the Ohio River can regularly be depended

upon to furnish sufficient rainfall during the crop season to produce maximum crop yields; they may, occasionally, but usually the rainfall will be such that the yield is reduced far below the maximum. Second, irrigation can be profitably employed in all our central valleys, and especially over the western plains, while in the more moist central valleys the largely increased yields will repay the cost of irrigation and give good interest upon the investment. Third, though the natural rainfall is much less than is required to insure maximum yields, still subsoiling and careful cultivation of the land will very materially aid in conserving this moisture and thereby greatly increase the present crop yields. Fourth, to again quote Professor King:

The evidence stands out clear and strong in favor of plenty of water in our soils all of the time a crop is making; for, it will be seen, we are comparing our irrigated yields with good large crops produced by the normal methods in humid climates in a season of good rainfall. And we must have an abundance of water in order that our crops may avail themselves of the plant food stored in our soils.

TOPIC No. 10.—EFFECT OF FOREST CLEARING AND CULTIVATION UPON, FIRST, WATER SUPPLY AND SOIL; SECOND, RAINFALL; THIRD, TEMPERATURE.

W. M. FULTON, Knoxville, Tenn., and GEO. N. SALISBURY, Seattle, Wash.

MR. FULTON. Popular views concerning the relation of forests to soil and climatic conditions were promulgated with the earliest history of climatology, but the scientific consideration of this important question scarcely antedates the middle of the present century. Realizing, as every thoughtful mind does, that it is only through strictly scientific methods that correct conclusions can be reached, we must concede the fact that our knowledge of this subject is still in its infancy. Like all other newly evolved sciences, the crop of incontrovertible facts is still scant, and further research will be necessary in order to solve the many complicated problems which present themselves.

Systematic observation and study along this line, based upon scientific principles, have been taken up by the leading countries of Europe and also in India, and the results which are being attained would form an interesting theme for discussion. But the limited time at our disposal here precludes the attempt at anything more than a brief review of the general and well established facts concerning the effects of forest clearing and cultivation upon water supply and soil and upon rainfall and temperature. Having thus merely introduced the subject I will leave it to my colleague, Mr. Salisbury, to present to us some of the more interesting details. For the sake of convenience we will consider the subject before us under three main divisions:

1st. The effect of forest clearing and cultivation upon water supply and soil.

2d. Upon rainfall.

3d. Upon temperature.

Before entering upon a discussion of these relations, however, I wish to emphasize two important physical laws in which are to be

found the explanation for much of what follows. These laws are : first, any obstructions upon the surface soil, whether natural or artificial, which prevent the rain water from flowing away as it falls, will increase filtration and underground drainage, and hence prevent washing of the soil. The second law is: The air being a very poor absorber of direct insolation has its temperature controlled by the temperature of the surface upon which it lies.

With these two important laws in mind, let us turn our attention to the consideration of the first division of our subject, viz, the effect of forest clearing and cultivation upon water supply and soil.

In order to get a thoroughly practical view of this matter, for all scientific discussion should be practical, let us suppose that we have here before us one of our American farms. In this farm are 2,000 acres of land, of which 1,000 are cleared and under cultivation, and the other 1,000 are forest land. This farm lies in such a way that the forest and field each forms a separate watershed to itself. Now, suppose that within a certain period of time, say twenty-four hours, one inch of rain falls uniformly over this farm, on forest and field alike. What will be the effects produced upon the forest as compared to those produced upon the field?

A portion of the rain drops which fall upon the forest will be intercepted by the foliage of the trees and the water thus collected will run down the twigs to the branches and thence down the trunk of the tree to the ground. The drops which penetrate through the foliage will strike the dead leaves and fallen branches upon the forest floor and their force will thus be broken without packing the soil. The surface soil of the forest having been rendered mellow by the roots of the trees which penetrate it here and there is also covered with a thick humus of decaying vegetable matter which holds the water on the surface, thereby insuring filtration and underground drainage, while the shade of the forest retards evaporation. The rain, therefore, which falls upon the forest will be fed to the nearest water course by the slow process of underground drainage, and the water course which thus receives its supply from the forest will maintain a comparatively even flow, and will not be subject to sudden and violent overflows, except in extreme cases.

In the case of the open field, the first rain drops which fall will pack the soil, thereby retarding percolation and filtration, and the excess of water thus collected will rush down the slopes, carrying more or less of the soil with it. Upon reaching the water course it will soon fill it to overflowing. The soil, too, which has been carried down by the water will sink to the bottom and thus aid in filling the stream. Soon after the rain has ceased to fall the water supply will become exhausted and the flow of the water course will be reduced to the opposite extreme.

Hence, it is plainly evident that the tendency of forest clearing and cultivation is to produce extreme fluctuations of water supply and to exhaust the soil by washing. Practical illustrations of this are to be found almost everywhere. Along the banks of the Ohio River and in many portions of the South hundreds of fields which were once covered with sturdy forests, and which under cultivation after being cleared, bore abundant harvests may now be seen furrowed with gullies as with the wrinkles of age, and abandoned to brush and briars. In France, the government and farmers together have, of

late years, spent over \$40,000,000 on reforestation and other methods for reclaiming washed soils. Some writers have supposed, and correctly too no doubt, that if the entire watershed of our great central valleys was cleared of its forests and placed under cultivation, the farmers along the lower Ohio, Mississippi, and Arkansas rivers would be visited by overflows of almost incalculable violence, and these would be followed in turn by unprecedented drought.

The next division of our subject, the effect of forest clearing and cultivation upon rainfall, is a matter to which we can only give a passing glance. Some writers hold that the forest has an attraction for the rainfall, and hence more rain will fall in the vicinity of forests than in extended open field. While certain observations seem to indicate that this is true, it still remains a question of serious doubt; even should it be found that rain falls more frequently and in greater quantities over forests than in the field, it seems highly probable that the difference is so small in amount that its effects are inappreciable.

Lastly, as to the effect upon temperature. The crown tops of the trees act in a manner very similar to that of any elevated surface. The absorption of direct insolation by the forest soil is largely restricted during the day, and radiation is similarly restricted during the night. The stratum of air between the forest floor and the crown tops is thus maintained at a more even temperature than that of the air in the open field. In this respect the effect of a forest upon an adjoining field strongly resembles that which would be produced by a neighboring body of water, except, of course, it is not so marked. This moderating effect is generally greater in summer than in winter, and is largely dependent upon the character of the forest and of the soil upon which it stands. The effect of the crown tops upon temperature does not appreciably depend upon the elevation above sea level. Much might be said here concerning soil temperatures and temperatures in or above the crown tops, and many other interesting details might be discussed, but limited time forbids further remark on this subject and I must hasten to a close.

Attention has already been called to the urgent need for more extended observation along these important lines. Nowhere, perhaps, among the more enlightened nations of the earth is this need more keenly felt than in our own country. The climatologists of France, of Germany, of Austria, and of India, may establish general facts, but they can not tell our legislators when and where to check the inroads of America's mighty and progressive civilization upon her primeval forests, nor can they tell the American farmer just how and where he shall clear his land for cultivation. These are questions which depend almost entirely upon local peculiarities, both of soil and climate, and the problem must be solved for each locality to itself. I believe I stand to-day before the ablest body of climatologists ever assembled in this country, and it is to you, gentlemen, that your fellow countrymen are now looking for the solution of these vexed problems. We are to account to coming generations for the progress made in this age along this line. Let us then, each and all, be up and doing.

Mr. SALISBURY. The effect of forest clearing and cultivation on climate is a question which has occupied not only students of meteorology, general scientists, and experts on forestry, but many

other thoughtful persons who have paid no special attention to meteorological problems. No satisfactory conclusion has ever been reached. Much of the subject is still debatable ground, and it will not be expected that I shall announce any new discoveries, or throw any light on the subject here. My purpose is simply to bring the matter to general attention, as one of absorbing interest if investigations are pursued, and one worthy of the profoundest thought.

The "forest primeval" encountered by the sturdy pioneers of this country is no longer of unbroken extent. It is rather a thing "of shreds and patches," admitting that some of the "patches" are good-sized ones. The settler's axe, in part, but more largely forest fires and the swiftly moving saws of the lumbermen, have cleared enormous tracts where lordly branches once waved, or the winds sighed and moaned through the pines. Sharp, glistening plowshares have coursed through the soil, turning the moist earth to the sky and sun; ditches have been dug, swamps and even lakes have been drained, fields of corn and wheat have been sown year after year, and the whole broad face of Nature changed. Most of this has been done within this century, much of it in the last quarter. Have not such sweeping changes had a marked effect on the climate, causing great changes in the nature of the soil, the rainfall, and the temperature? Some argue, with great show of facts and figures, that it has; others, with equal force and greater positiveness, that it has not. And either side may be right, for the question is debatable. I maintain that the time has been too short, observations too few and limited, and investigation too biased for the problem to be determined one way or the other.

Not many years ago, as history is recorded, but a short lifetime, as men view time, there was an immense unbroken forest in Wisconsin and Minnesota. Through the denser parts of these forests were many considerable watercourses and large lakes. South and west of the great pine forest, in a belt of deciduous trees, were scattered thousands of small lakes, and, on the prairies beyond, many more lakes and innumerable marshes or swales. Forty years have passed and what is the present condition? Fertile but sometimes drought-stricken fields occupy the southern part and beautiful farms cover the belt of oak openings. But the swales are gone, and many of the lakes have totally disappeared. Others have dwindled until two-thirds, one-half, or less than a third of the original area remains. The streams have become so diminished in volume that with great difficulty the log drivers float their smaller logs of culled-out timber to the Mississippi, where formerly immense drives of the largest timber were made with ease. Every summer, reports of great and unprecedented heat and long periods of drought fill the newspapers. Has there really been a change in these conditions? And, if so, was it not the forest clearing and cultivation that did it?

The old settlers will instance the above changes to you, and scarce one of them but believes the clearing and settling up of the country has accomplished them. The writer was born in Minnesota and lived there from infancy to early manhood. He has the evidence of his eyes for proof of the diminished streams and lakes. He believes, too, that the rainfall has lessened, but does not know, for there were no rain measurements in the forest regions in those early days; but the infalls seemed much heavier in his early boyhood than twenty

years later, when he measured them at the station in St. Paul. However, personal impressions are not a safe guide in such matters. Reports were often rife of temperatures in the nineties during the early days, but there were then few standard thermometers and fewer proper exposures. So there is no evidence that the summer temperature has not increased and none that the summer rainfall has not decreased. In the early records of the frontier forts and the French trading posts I have not a great deal of confidence.

In the far Northwest, from the western slopes of the Cascades to the seacoast, fed by moisture-laden air from the ocean and the heavy rains precipitated on these slopes, there sprung up long ago the mighty, almost unending forests of gigantic trees. These great conifers, that have given to one of our Union the title "Evergreen State," were twenty-five years ago scarcely touched by the hand of man. In a few short years the ravages of the axe, the gang saw, and, greater still, forest fires, have been so vast and alarming that the National Forestry Association felt impelled to secure an executive order setting aside great areas, large enough to form small States, as permanent forest reserves. Their fear and argument was not solely the commercial effect of the loss of the timber as a source of wealth, but also a disastrous effect on the mountain streams, lakes, and the soil of the country; perhaps, also, on the climate.

Even those who deny any appreciable meteorological effect admit disastrous effects on the soil from wholesale forest clearing. The presence of forests retards the melting of winter snow, which otherwise melts suddenly, allowing the water to rush in great volumes down the slopes, resulting in damaging freshets. The roots of the trees hold the soil together, which otherwise would be moved by the rush of torrents of water, and rubbish, sand, gravel, and boulders washed down and deposited over fertile bottoms, destroying the value of the latter. In dry spells the springs and small streams dry up and disappear because the unsheltered soil is exposed to evaporation; much more so if the process of cultivation has upturned the bare earth where there would else have been a covering of grass or undergrowth.

Some admit even more, by allowing that evaporation, being retarded, and moisture held in suspension over the forests, more constant, moderate, and uniform rains occur, while extensive clearing makes the rainfall more intermittent and torrential. Long periods of drought occur, broken by excessive rains of very short duration. The climate, in short, begins to resemble that of the great treeless plains in the nature of its precipitation.

Some of the most noted meteorologists have maintained that a permanent decrease of average yearly precipitation or permanent increase of mean temperature is impossible as a result of forest clearings; they hold that the causes that contribute to rainfall over a large tract of country are of too widespread and general a nature to be permanently affected by such minor changes in the face of Nature as the removal of a forest growth or the cultivation of the soil. This is simply saying that general rainfall over a given area is the result of a moisture-laden wind from the ocean or large seas moving over or contiguous to that area, and that such a disturbance covers thousands of square miles in area and reaches high into the atmosphere; it has crossed mountain ranges, perhaps, without breaking up, and is not to be

swerved from its course by the presence or absence of forests. Very true; and none of us who have followed the daily maps would venture to differ from the leaders of meteorology on that score. But what humble observer with experience, much more the baffled forecaster, has not learned that even in great cyclonic movements rainfall is the most local of all things meteorological? What local forecaster has not predicted rain for his station on account of a general low-area storm, and yet "missed it," although he subsequently learned that copious rain had fallen not three miles away? So I believe it possible that the distribution of rain—monthly, seasonally, perhaps even annually—can, by forest clearing and cultivation, be changed over small areas, yes, even over whole States, though not whole countries like our Union of States. Nor is the latter necessary to my argument. Rain being of so local a character in the general cyclone, forests might well be a cause for condensing over their area or in their neighborhood continuous though gentle rains from even the feebler low areas, while the treeless tracts would receive only occasional, though perhaps excessive, rains from only those of decided energy.

Prof. William Davis says:

Popular opinion is disposed to believe in an increase in the rainfall of our semiarid western plains by means of tree planting and agriculture, but no evidence in the form of actual records has been adduced to prove this very hazardous conclusion.

During his residence of some years in Utah, the writer became aware of a general belief that the settlement of Salt Lake Valley, and the general cultivation by irrigation and the planting of a great number of trees had had a noticeable influence in increasing the rainfall and water supply, so that if it went on there would finally be little need of irrigation. He was unable to verify this from records, but, as I have before indicated, the records previous to the establishment of the signal station there were very broken and uncertain, and would prove or disprove nothing. The testimony of the inhabitants was positive that several mountain streams, which formerly had gone dry in summer, were now permanent.

In the Evergreen State, where I have had the good fortune for some years to reside, and in the adjoining State of Oregon, there are, as you well know, two divisions of each State, more different in their climates than any two adjoining States you can name. The eastern sections of the States referred to are dry in climate, while the western sections are moist to wet. Warm, moisture-laden storm movements from the ocean, striking first the coast ranges, lose by condensation from adiabatic cooling in the ascent a large amount of moisture which falls as excessive rain during six to nine months of the year. Still eastward rain falls as it ordinarily forms by adiabatic cooling over the intervening country to the Cascades. There, in passing the mountain barrier, the greater part of the remaining moisture is precipitated by the same process of adiabatic cooling, so that but little moisture remains for the great plains of the Yakima and Columbia rivers, while the southwest to northwest winds, warmed by the double effect of liberated latent heat, and dynamic heating in descending the eastern slopes, become the chinooks of that section, like in character to the foehns of the Alps. And here let me digress merely to

repeat of those chinooks what Professor Waldo has so well said of the foehns:

The degree of intensity in the foehn (chinook) depends on the amount of water lost by condensation high up in the mountains, and on the distance of the descent of the air. If no water were lost out of the air there would be no foehn (chinook).

Over the immense region west of the Cascades, then, the rainfall is heavy, and though it is doubtless true that such an immense forest area naturally grows up where the climate is moist and rainy, it is perhaps also true that the great somber forests have a reciprocal effect in making the regions more rainy. This is speculation to be sure, but it seems as though the great low-area storms have a peculiar tendency to linger over the forest region and western slopes of the Cascades, retarded often for days at a time with no apparent cause. Then, as with a bound, they pass the summits, and the low areas move rapidly to the east-northeast. In fancy, then, I see as a result of the disappearance of the great forests of Washington (as disappear they surely will at the present rate in three or four generations) a great change in the two contrasting climates. The storms will pass more rapidly across the western part of the State, precipitating less of their moisture, and appear east of the mountains with a greater amount, which will then fall over eastern Washington. Thus, the result will be beneficial, climatically speaking, and twofold; the western section now too moist will become less moist, the eastern section now too dry will become less dry, making fertile the arid lands along the Columbia. A consummation devoutly to be wished, you say, but too fanciful. Perhaps not. It is indirectly proven even now. For the past two or three years there have been unusually heavy summer rains in eastern Washington, contributing to unprecedented wheat crops. In June of 1897 the rainfall was singularly heavier east of the mountains than west of them. So also at times during the past summer. Why? Under what conditions did this anomaly take place? It occurred wherever the low area reached eastern Washington without being robbed of its moisture by passing over the western section. This happened when the area moved up from southwest Oregon, or rapidly up the Columbia Valley, or even when the storm passed without lingering across the Cascades. In such cases the east side always received its maximum rain. So I believe if we grant that forests have an influence in retarding storms, their clearing will result in changing the climate as stated. Some years ago a Nevada correspondent of the Salt Lake Tribune made this claim for Nevada, namely, that the clearing and burning of forests on the Sierra Nevada had increased the precipitation in Nevada.

Returning from the field of fancy to that of facts, and to the diminished streams, swamps, and lakes of Minnesota, it is not necessary to suppose a diminished rainfall to account for what we have noticed there. Forest clearing allows the snows to melt rapidly in the spring, the streams to rush away in sudden freshets, instead of a gradual flow through the summer. Cultivation of the soil upturns to the sun an immense expanse of earth from which the moisture evaporates, instead of having remained in the soil as it otherwise would. Many of the lakes, sloughs, and swamps of Minnesota have been drained for cultivation, and the writer well remembers seeing miles of ditches excavated during his boyhood. As Prof. Cleveland Abbe has aptly said:

Every acre of virgin soil that is plowed up and cultivated begins to evaporate into the air the moisture that it formerly conserved. Similarly every new drain that is dug helps the water that formerly staid in the soil to flow off into the rivers. The progress of agriculture begins by an effort to drain the rich lowlands that are usually too wet, and ends by the necessity of artificially watering both the dry uplands and the warm lowlands. In other words we begin by evaporating and draining off the water that we eventually wish we could get back again.

Professor ABBE. I think the quotation from Abbe is all right, but Abbe had in mind New England and European conditions. What he said is true for a large part of the world, but not universally.

Mr. HAMMON. Two or three years ago I read in Science a paper which is so absolutely contrary to anything I had ever read on the subject that I think it is worth discussing here. It was by a man from Nevada, and he declared that there was excellent evidence that the denuding of the forests of the Sierra has actually increased the water supply during the summer; he did give very good reasons for his belief and cited facts to show that the streams held their water in summer much better since the timber was cut off. The forests are of pine, and he claimed that the snow melts faster when the trees are standing than if they were not there. When the forests have been cut off all the snow blows into the cañons, hundreds of feet deep, stays there all summer, and keeps up the water supply. When the trees stood, it formed a blanket over the ground and melted much more quickly. Of course this is a local condition, but it is the region whence we get our water, and if the cutting off of the trees is going to increase our water supply in California, we shall be very glad to have them cut off rather than preserved.

Mr. SAGE. I have made the conservation of moisture in the soil a special study for twenty-five years in Iowa. I believe the effect of deforesting any area depends upon the geological formation and the character of the country. If it is a hard, rocky country, like some portions of the east, with an excess of rainfall, then to cut off the forests allows the soil to be washed away, whereas in our region the cutting off of the original forests has no appreciable effect whatever upon the surface moisture, in my opinion. I believe the subsoiling of our prairies, where we have humus 4 feet deep, prepares the soil to receive and retain moisture better than the eastern forest, with its hard subsoil. In other words, we can store away within our prairies, if they are properly cultivated, subsoiled, and drained, more moisture, and keep it through the season for the benefit of plants, than they can in any forest region in the east or north. I believe our subsoiling and our method of cultivating prairies is more than equivalent to covering with forests any area of the same extent; that is, with our deep soil. In the east I would advocate reforesting large

portions that have been deforested. But here trees act as robbers of the soil as well as conservators of moisture. Trees are detrimental in prairie farming sometimes. You can not get a row of good corn for two rods alongside a row of trees. So this question has a good many sides to it, and it depends altogether upon the locality and the nature of the soil whether forestry is important or not from a practical agricultural standpoint.

Professor HAZEN. This subject is of the utmost importance, and you gentlemen from all parts of the country ought to have some pretty clear ideas as to the effects of forests upon rainfall. While I do not believe that the presence of forests increases rainfall, yet I believe most emphatically that it conserves rainfall. Then if you have forests there will be springs. In New England the springs are drying up because the forests have been cut away. So, we have positive information there from the drying up of the springs of the effect of cutting away the forests. While I agree with Mr. Sage that the cultivation of the soil will prevent a good deal of moisture from going to the streams, it seems to me that at the same time this very cultivation will allow a greater evaporation, so that you lose moisture in that way. The very article in Science that Mr. Hammon referred to was answered by two or three individuals who showed that the effect of piling the snow into those cañons was simply to increase the flow of the stream out of the gully, but the larger area was drier than before. I say emphatically that the cutting-off of the forests would give us a dry land.

Mr. J. WARREN SMITH. I have in mind a spot on a mountain side in New Hampshire where there is a clearing surrounded by woods above and below. In the wood above the clearing, water stands in the streams all the year round; in the clearing it is all dried up; and below the clearing there is water also. I think the Weather Bureau should take up this question in a practical manner. Regular observation stations should be established and carried on long enough to determine this point. There is a difference of opinion on it. Stations of observation should be established upon streams flowing from heavily wooded sections and from districts where the old growth forests have been cut off. A record should be made of the precipitation, the flow of streams, the depth of water content of the snow on the ground, the condition of the soil under the snow, and the exact conditions preceding and following a flood. Record, and that alone, will determine the facts in the matter. The editor of the American Cultivator has contended that heavy forest growth consumes more water than it conserves, and that when the ground is frozen a thaw with a warm rain must precipitate a flood. Yet it seems very unlikely

that the ground would be frozen enough under a heavy forest growth to prevent water from melting snow to percolate freely into it in an innumerable number of places, and we are all sure that snow remains to an appreciable depth in the woods, when the ground is practically bare in the open and the underbrush.

The treasurer of the Amoskeag Manufacturing Company, of Manchester, N. H., said, in part in an annual report, a few years ago:

On April 15, 1895, there occurred the highest freshet until then known in the Merrimac River. * * * We worked all that summer to repair the dam, etc. Had it not been for these repairs the dam and the gatehouse would probably have been carried away in the freshet of March 2, 1896, and all the mills in Manchester stopped for an indefinite period. As it was, the water rose one and one-half feet higher than the previous spring, carried away our bridges as well as the city bridge, compelled us to stop work and left 6,000 operatives without employment. When you consider that the Merrimac has for the past few summers been lower than in previous years, it is evident that some cause is at work turning the stream into a torrent, with long droughts and fearful discharges of water. There is but one explanation in my judgment, of this phenomenon, namely, the cutting down of forests around the headwaters of the Merrimac, the Pemigewasset and other affluents. * * * I appeal to you, gentlemen, for the interest of New Hampshire, which depends so much upon the success of the manufacturing corporations situated upon the Merrimac and the other streams of the State, to exert your utmost influence to induce the next legislature to protect the forests remaining. The damage done is already most serious, and if this state of things continues, manufacturing by the water power of the Merrimac will become, in my judgment, impossible in New Hampshire. * * *

Mr. SAGE. Not only does deep cultivation allow the soil to take up moisture, but the stirring of the surface keeps it there. In other words, you put a cap over it when you have it there. That is where cultivation comes in to conserve moisture.

Mr. MITCHELL. This is such an interesting question, and there are so many varied sides to it, that I would like to cite the experience of one of our voluntary observers in Florida. He has lived in Florida forty years, and came to my office purposely to ask a question relative to the conditions we are discussing. He said that for twenty-five years, to his certain knowledge, there had been small lakes in that country, which is flat, over which he had to travel with his cart, but within the last five years this water had disappeared entirely and there was now none to be found. These pools had dried up and yet the annual rainfall did not show any deficiency.

Mr. BAILEY. In Fort Smith, since I have been there, I have talked with some who are interested in the river reports, and they state that they used to have a regular general rise but do not have it now. The engineer of the Government at Fort Smith said they never have had a regular general rise in the Arkansas River. I have never had a chance to examine the statistics to see which is right.

HAMMON. Regarding irrigation in our State and its effect: In all season Tulare Lake does not cover one-third of the area it

did twenty years ago, because of the draining away of the water for irrigation purposes. This year there is no lake at all. When they first began to use the water for irrigating purposes, the people down stream protested. It became a great subject for legislation, because the people farther down would be without water. It is a fact that when the water from rainfall meets the permanent supply of water in the soil, which is only a few feet below the surface, we get a crop in California. When a space of dry earth remains between the two, we do not get a crop. Now the result of draining the water of these streams from along the foothills for irrigating purposes has brought that low water much higher, so that the old beds still hold water lying in pools all summer long when twenty years ago they were perfectly dry, and we get a crop now with decidedly less water in places not irrigated, than used to be necessary.

Mr. BATE. A few years ago I traveled through California and spent some time in the San Joaquin Valley. I was particularly interested in that raisin country. I noticed round the city of Fresno miles and miles of the old irrigating ditches that had been dry for years, and the man who was with me said they had brought the water there years before, but found they had too much for their vineyards and turned it off. That country was absolutely dry, and yet it was one of the grandest vine-growing countries I have ever seen.

Mr. Bailey spoke of a "June" rise in the Arkansas. A residence of several years on the lower Mississippi and close observation of conditions on that river, impressed him with the effect of a "June" rise on the country and the crops. The cotton planters had a very wholesome dread of a "June" rise. Floods in the river caused by spring floods above on its tributaries were not so much dreaded, although sometimes they caused a greater overflow; but when a general rise came through the melting of the snows in the Rocky Mountains, the conditions produced were most disastrous; something like the flood of last year.

Mr. BRANDENBURG. We need never fear a disastrous flood from melting snows in the mountains unless we have heavy rains to produce melting. Natural melting without rain never causes a flood.

Professor MOORE. This subject is such a fruitful one that we might profitably continue its discussion for a week. It is extremely difficult to base any conclusion on mere hearsay evidence. Old citizens will come in and tell you a stream is dried up or the water in the well is not so high as formerly, and all from their own recollection. Unless you have accurate data to discuss, it is utterly useless to attempt to reach any conclusion. Now, Mr. Mitchell stated that a number of

ponds in the State of Florida where the land was perfectly level had passed away. It is certain that if there were ponds, there were also depressions which caused drainage in their direction. Now that drainage, although the movement of water was slight, carried alluvial deposits into the depressions. These deposits, with rank vegetation, have simply filled up the ponds. The water is there, but below the surface of the earth. A mistake that most people make, in claiming that there has been a change of climate in their region, is due to the fact that change is continually going on in the surface of the earth, due to the action of temperature and water. That is what causes your streams to fail and your ponds to pass away. Now, you may drain with tiling and other methods and you will alter the character of a small area; but I venture to say that all the draining done in the United States and all the deforestation have been immaterial, inappreciable, in their effects on climate. They may have had an effect in augmenting floods, by rendering it possible for a given amount of water to gather more quickly, and thereby supply streams with a greater volume to carry away in a given time, producing flood stages. I can see practically no other effect of deforestation or of the drainage of the surface of the ground by tiles than simply to augment the intensity of the flood volume. It has no effect on climate. But the subject is such a fruitful one, as to what is the effect of forests on the conservation of moisture and the effect of the cultivation of forests on the consumption of the moisture in the soil, that it is a grave question whether the planting of forests does not result in the consumption of more soil water than the foliage retains by shading. There has been much written on this subject, and it is nearly all on very imperfect data, and we have very few facts on which we can talk with any certainty; but it is so interesting that I encourage you to study the subject in your sections. Don't take hearsay, and don't take what the oldest inhabitant says.

Mr. Sage said there was a great lack in many States, and especially in Iowa, of rainfall data. One station in a county for rainfall measurement was not enough; we should have ten; if possible, one in every township.

TOPIC No. 11.—IS THE WEATHER MAP APPRECIATED AND UNDERSTOOD BY THE MASSES? WOULD NOT THE POSTAL CARD WEATHER FORECAST PROVE A SATISFACTORY SUBSTITUTE FOR THE MAP, EXCEPT WHERE IT IS USED FOR THE PURPOSES OF STUDY AND INSTRUCTION?

E. B. CALVERT, Washington, D. C., and T. F. TOWNSEND, Philadelphia, Pa.

Mr. CALVERT. Mr. Chairman and coworkers: In a brief paper that is referred to elsewhere in our program I have treated of the development of the weather map. The history of this important work of

our service shows that the mechanical problems in connection with the weather map have been overcome. It is now possible to issue as many legible copies as may be required. But now another important question presents itself, one that must be considered carefully and intelligently. During the year ended June 30, 1898, over 5,000,000 maps were issued to the public from the stations of the Weather Bureau. They were sent to people representing nearly all the different lines of commercial and professional life. What percentage of these persons used the charts intelligently, understanding the drift of the highs and lows and the weather conditions that usually accompany them, and what percentage merely used the printed forecasts, ignoring entirely the map itself? These are difficult questions to answer, but they are vital questions. If any considerable proportion of the subscribers paid attention to the forecasts alone, then the less expensive and more easily prepared bulletins and forecast cards would have answered every purpose. For over ten years the weather charts have been issued to the public, and in every community they have been conspicuously posted. Are these charts better understood and more intelligently studied now than they were ten years ago? Our station officials may differ in answering this query, and their opinions will be interesting. For several years the Washington Evening Star published conspicuously a reproduction of the morning weather map. It was one of the features of that paper. A few months ago it became necessary to use the space for other matter and to discontinue the chart. It was fair to presume that in such a community many letters would be sent to the Star in regard to the discontinuance of the map. Only three such communications were received. Does this indicate that the public does not understand and appreciate the weather maps?

We have brought our map making process to a satisfactory stage; now it is important, as far as possible, to confine the issue to those who desire to make intelligent use of them and can do so. This is not an easy task. It is not possible to investigate each individual request and ascertain whether or not the chart to be furnished will be advantageously studied, or simply placed in a frame to be regarded as a mystery by the majority of those who stop to examine it. It might be advisable to discontinue the maps issued at small stations and replace them by bulletins, or forecast cards, without impairing the efficiency of the service, and at larger and more important stations to keep the issue as small as possible by a judicious inquiry into the uses to be made of the charts by applicants. It is possible in many cases to meet the needs of persons requesting the maps by sending them forecast cards instead. Most of our station officials exercise great care and judgment in this matter, but still the map list grows. This increasing demand might be taken to indicate that the public is becoming better informed in regard to the charts and their value. In some sections this is probably true, but in most instances it can be attributed to the desire of the applicants to get the charts because others get them and because they are furnished free. To those not acquainted with station work this argument may seem weak and insufficient, but the station officials know that it is true.

Since it has been decided to discontinue the use of the large size station map, and use instead the small chart, the aggregate cost of

the maps will be considerably decreased. This smaller chart can be prepared almost as quickly and cheaply as a bulletin, as but one small piece of stencil paper is required. This being the case, no material advantage would be gained by issuing bulletins at small stations instead of the maps, but if the predictions alone are appreciated by the public the forecast cards can be furnished easier and far more economically than either the bulletins or the maps.

The station maps in blank cost the Bureau about \$1.55 per thousand, while the same number of forecast cards cost but 40 cents. The expense of preparing and issuing maps is far greater than the expense of sending out cards. It is not economy to deny the maps to those who can gain information and profit from them, but as trusted public servants it is incumbent upon us to use due diligence in their distribution and to guard against unnecessary waste. The whole matter is worthy of discussion.

Mr. TOWNSEND. In answer to the question "Is the weather map understood and appreciated by the masses?" I would say, emphatically, no. Neither do I think they are by the majority of those who receive them. Most of the maps that are posted "for the benefit of the public" are placed in front of stores and other places for advertising purposes, and the public in passing look at them as they would a picture, and but few stop to study them. I believe, however, there are enough people that do and can make an intelligent use of the maps to warrant their distribution to the largest number practicable. The issue is necessarily limited, as they can not be prepared until the reports are received and the printing must stop before the closing of the mails. Because of this limitation, more care should be made in their distribution. A short time ago letters were sent out from the Philadelphia office to almost the entire mail list asking whether cards could be substituted for the maps, and nearly every answer was no, but they gave no reason for their answers. The maps are larger and nicer than the cards and cost more money, and when people can get something for nothing they want all they can get. I think there is one objection to the card as issued at present. A synopsis should accompany the forecast. In this way I believe it possible to get more people interested in the card. In order to give this additional information it will be necessary to stamp or print them in some form different from that in present use. The ordinary printing press is not fast enough. The inventive genius of the members of the Weather Bureau should be sufficient to get up some cheap instrument that will print them rapidly. Some means for addressing rapidly is desirable, and for this purpose I have constructed a device. I won't speak of its merits or demerits at this time, but would like to have you see what it will do.

(Mr. Townsend exhibited his addressing machine.)

TOPIC No. 12.—PAPER: PRIMARY WORK ON METEOROLOGY FOR THE USE OF SCHOOLS.

PATRICK CONNOR, Kansas City, Mo.

Mr. CONNOR. My experience during the past year or two has led me to believe that the Weather Bureau should compile a small, primary

work on meteorology, suitable for the lower grades of schools, for free distribution to schools and teachers, or at the cost of production which, of course, would be very small. I have mentioned this matter to teachers, clergymen, scientists, and others, and all were of the opinion that the idea should be carried out by all means, some of them being quite enthusiastic, especially Prof. J. M. Greenwood, Superintendent of Kansas City public schools, and President of the National Educational Association of the United States.

In the first place, there is not a primary work, a catechism, an elementary handbook on meteorology to be had; certainly none that fills the requirements of present needs. Waldo's and Davis' works are all right in their place, but a pupil must be ready to enter a high school to take them up. There should be a simpler work to interest and instruct children in the earlier grades. Meteorology need not be altogether treated as an advanced study to be taken up only when the grade of a high school is reached. It is estimated that only about 4 per cent of the children of the United States enter a high school or other institution of similar or higher standing. Now, what is being done for the remaining 96 per cent? Even in the high schools meteorology does not come within the curriculum, except in so far as it is treated in physical geography.

During the year ending June 30 last, the Kansas City office furnished maps to 175 educational institutions by request, less than one-fourth being up to the grade of a high school course. Much information was also given by our office upon the text-books available, the usage and cost of instruments, and how the study could be taken up in the schools, but it requires more than can be said in a letter to give them a start.

Another lamentable feature of the matter is that very few teachers have a knowledge of meteorology. It is not required of them in in order to secure a teacher's certificate. They are not furnished with text-books, and a great many are unable to purchase them because of meager salaries. It may be set down that the teachers and principals will not take up, in an incidental way, the teaching of something of which they have but a poor idea and which is not outlined or systematized in any available work. The course suggested by Professor Davis is far beyond them. The study must be made easy and elementary. The introduction of this branch into school studies is an innovation that must be presented in a simple and attractive form.

Then, again, public appreciation of the difficulties met with in forecasting, a feature of the Bureau's work which overshadows all else, will never be secured until the public has a better understanding of the subject, and the surest way to bring that about is through the schools, which will act as a leaven in their several communities. I have explained time and again in the newspapers, as doubtless many observers have done, how forecasts are made; what they are based on and the difficulties which beset the forecaster, as well as the unreasonableness of the public at times, but a failure is looked upon by the masses at present as if nothing had ever been said or written on the subject, and the great majority are just as prone to credit it to inefficiency.

All of us have been benefited by what we have been taught in schools and colleges; but is it not amazing that the prominent educa-

tors, those who decide and dictate what branches shall be taught in the schools of the country, have not yet realized the importance or practical usefulness of giving pupils an idea of the atmosphere in which they live; the phenomena which concerns every day of their lives; that which sets its seal on character and modifies hereditary tendencies.

It is understood, of course, that the schools in a few prominent cities have taken up this matter in a rudimentary way, but this fact does not lessen the responsibility of those who prescribe the courses for the various States and Territories.

The majority of children who receive only a smattering of certain scientific branches forget all about them within ten years after leaving school, simply because there was nothing in their daily lives to refresh their memories or revive recollections of them. Take botany and chemistry: I doubt if one in ten, within ten years after quitting school, could tell which way the seeds point in an apple, or give the chemical designation of common table salt. Whereas, with meteorology it is quite different. Instead of forgetting what they had learned, their knowledge would increase—thanks to Nature's free lectures and daily panorama.

My idea in suggesting this work is that, besides being a simple treatise on weather matters, it should contain instructions for teachers which would enable them to interest children from 7 or 8 years of age up to where their mental equipment calls for a more advanced work, and I believe that the primary education in this line would make the subject so attractive that it would soon become one of the preferred studies.

The instruction should begin with symbols. The teacher, in order to engage the attention of children 7 or 8 years of age, should draw flags on the blackboard to indicate the expected weather. After they become thoroughly familiar with the flags and their meanings something else should be added. The points of the compass should be drawn, and across them an arrow showing the direction of the wind; and, as they become familiar with the points of the compass and the designations usually given the winds, a little more could be added; but the flags and wind directions should be kept up every day. Now the teacher could write, for instance: "To-day the wind blows from the north. The weather is coldest when the wind blows from the north or northwest." "To-day the wind blows from the south. The weather is warmest when the wind blows from the south." Interest should be kept up by adding something new every now and then, thus: "The sun does not shine to-day because of the clouds." "Clouds are made of tiny particles of water." The subject can thus be developed from this simple beginning gradually to cover the readily recognizable features of the storms of summer and winter. There should be a short and simple description of the barometer and how it acts before, during, and after a storm; in other words, its application to weather changes. The dry and wet bulb thermometers should come in for their share, and the significance of their readings be explained, thus: When the readings are far apart the atmosphere is very dry; when close together, very moist, as in foggy weather. With high temperature and not much difference in the readings, you may expect to feel warm and uncomfortable; the air is very oppressive, because it is very moist or humid. Sunstrokes may occur

in the neighborhood. But with the same temperature and the wet bulb reading 15° to 20° lower, you do not feel uncomfortable in a slight breeze, because the air is very dry. Further on explanations of these facts can follow.

At this time the children should be required to record daily the reading of the barometer and thermometers and the direction of the wind.

A general conversation should be given in the work on the physical aspects of storm areas, the names and elevations of clouds, and how clouds and rain are formed. The children should now be called upon to record daily, with other things, the names and amount of clouds and the state of weather.

It should be suggested that teachers should elaborate their explanations, which frequently prove to be very instructive outside the immediate point at issue. Frequent reviews should also be called for.

The titles of the best American works on meteorology to be read after this primary course should be given, and the cost; also, the cost of ordinary and good barometers and thermometers.

The daily weather maps and how they are made should be explained, how to compare them to get the sequence of changes, and an allusion to the many hidden beauties discoverable after a little study.

There is a great necessity for a work of this kind. Its issue by the Government will not be usurping the privileges of publishers or authors. It will be a parallel case with the issuance of other scientific and semiscientific papers, constantly being published, for public enlightenment. In fact, it is believed by the writer that it would stimulate the sale of standard works on meteorology, as very few teachers would stop investigations with the knowledge gained from this primer. The attractiveness of the subject would arouse interest in teachers and pupils who, perhaps, never would have understood the difference between a barometer and a thermometer if it had not been for this simple but valuable little book.

If the Bureau is anxious to have this study taken up in the schools of the country, this is the only rational and systematic method by which it can be accomplished.

Professor Greenwood, in a letter on this subject, dated July 25, 1898, says:

The suggestion that a small volume be prepared by the Weather Bureau, stating explicitly the simplest principles of the science of meteorology for the use of the teachers and pupils in the schools of this country, meets my unqualified approval. I sincerely hope your efforts in this direction will receive consideration at once.

TOPIC No. 13.—SHOULD NOT CERTAIN IMPORTANT WEATHER BUREAU STATIONS, THE DUTIES OF WHICH COVER A WIDE RANGE OF WORK, BE DESIGNATED STATIONS OF INSTRUCTION FOR NEWLY APPOINTED OBSERVERS?

J. WARREN SMITH, Columbus, Ohio, and C. F. R. WAPPENHANS, Indianapolis, Ind.

Mr. J. WARREN SMITH. This idea of stations of instruction was suggested to us by the fact that our office has been burdened with new men this summer who, while unable to take hold of any important duties in a trustworthy manner, have actually made the older men more work by their inexperience. I believe that it is a detriment

to the satisfactory work of a station to have new men put in an observer's place and supposed to fill it, so far as the work of that office goes. The absolutely new man must make more work than relief if he is being properly instructed. The result of the present system oftentimes is that while, theoretically, the new man may be taught all the details of the work, he is actually set at that work which is simplest and which he can do most readily and rapidly, or which the older men dislike.

Perhaps he is first put on a small station with a limited variety of work. He does a portion of that limited variety of work in a highly satisfactory manner, is favorably reported on, and is sent to a large station as an experienced man, but he is like a new man to the latter station.

I believe that certain centrally located stations that have a great variety of work should be the centers of instruction, for instance, one west and one east of the Mississippi, and that when new men are sent there the regular office force should not be disturbed. It would be well to have certain men at these stations designated as instructors, who shall train the new man carefully, report on his progress to the official in charge, or directly to the Central Office, and then, in a measure, be responsible for the observer's fitness when he finally is given regular duties.

Mr. Wappenhans spoke briefly of the danger of entrusting even simple work to new hands and deprecated removing an assistant as soon as he had become skilful.

Mr. BATE. I heartily agree with the gentlemen who have made these very appropriate remarks. I have had a sort of kindergarten at my station during the present year. I have just finished with one pupil, and the happiness of this meeting has been marred to me, to a great extent, by the knowledge that I have to go back home and take another kindergarten pupil. My man, who had just finished his six months' probation, is ordered off to Santa Fe. I think it would be a decided economy to establish these proposed schools of instruction, and when a man comes to a station let there be some assurance that he will come fully equipped.

Mr. Mitchell thought the school was already established, namely, at his station. He would soon have a couple of graduates ready for some one.

Professor ABBE. I think you all must have been troubled by the changes in the young men. I can only wish that the Chief were here to hear these valuable suggestions.

TOPIC No. 14.—CLIMATE AND CROP SERVICE WEEKLY BULLETINS: SHOULD REMARKS OF CORRESPONDENTS BE PUBLISHED AS SUPPLEMENTARY TO GENERAL DISCUSSION? SHOULD WEEKLY REPORTS OF TEMPERATURE AND RAINFALL BE TELEGRAPHED TO SECTION CENTERS FROM SELECTED VOLUNTARY STATIONS?

A. E. HACKETT, Columbia, Mo., and J. B. MARBURY, Atlanta, Ga.

Mr. HACKETT. In regard to publishing correspondents' reports, I have always thought that was one of the most important features of the bulletin. In Columbia I have met quite a number of the farmers of Missouri, particularly the more progressive ones, who come to the university to attend the short course in agriculture, which lasts two or three months during the winter. I have shown them copies of the bulletin and asked them what they thought of it. Almost without exception they have said that the reports by counties were the most interesting and valuable to them. The summary, which is placed at the top of the bulletin and which is published by the newspapers, gives a very good idea of the general conditions over the State for one who wants to read hastily and get a general view of the conditions, but many farmers are interested not only in the State at large, but in particular crops cultivated principally in certain sections, and they want to see what the reports are from those sections. I think the publication of extracts from their reports is of fully as much importance as the bulletin itself. But as to the best method of publishing these reports I am a little in doubt. Prior to this year I used to take the crop reports as they came in and place them together by counties. Then, in writing up the bulletin I took the reports from each county and tried to take one sentence from each man's report, putting in something like "Corn is doing finely," or "Too wet to plant," and so on. I tried to get a short sentence out of each man's report, something he would recognize, and published only the name of the county, not giving the name of the reporter at all, nor the name of the place. Up to this year I had about 300 to 350 names on the crop reporting list. Of course we all know a great many correspondents do not make reports regularly, and others are as regular as clockwork, but I seldom had occasion to drop from our bulletin mailing list, a man for failing to report. If he reported twice a month I kept him on the list, rarely having occasion to drop one. This year the list was increased to 500, and I think about the 1st of June I began to publish the names of the correspondents. I had room in the bulletin for about 76 reports; there are 114 counties in the State, and consequently I could not give the reports for each county, so I took them in rotation and the correspondents' reports in rotation, stating in the bulletin that that would be done. Our bulletin fills the entire sheet, the summary being set in solid primer and the correspondents' notes in solid minion. I published the name of the county, the name of the place from which the report came, and the name of the correspondent. This prevents any misconception or misunderstanding that might arise under the other plan of publishing only the name of the county, for it frequently happens that the conditions in one part of the county are entirely different—perhaps just the opposite of those in another; a man in the north part may report that corn is suffer-

ing for rain, while in the southern portion there may be an abundance of moisture. In such a case, if only the name of the county is published, the people in the southern portion are very likely to say that the report is not correct, and that the bulletin is unreliable and misleading, but when the name of the place is published such adverse criticism is avoided, and the publication of the correspondent's name not only gives him due credit for his work, but tends to make him more careful and conservative in his statements. But while I thought the change from the old plan a marked improvement, I very soon found a decided falling off in the reports. Correspondents could not understand why their reports were not printed, and they wrote and wanted to know. I had to write a great many letters of explanation, and even then a good many thought they were slighted.

Mr. MARBURY. The great value of the weekly crop bulletin lies in the fact that it carries to its readers each week the condition of the various crops, showing the effects of the weather, whether for good or evil. Now, the question arises what is the best form in which to present this information? Whether by a general summary of the conditions of the entire State or a condensed summary followed by the remarks of individual correspondents. That there seems to exist a diversity of opinion as to the best means of giving this information to the reader can be seen by a glance over the bulletins of the different sections of the National Climate and Crop Service. That there should be some uniform style adopted is beyond question. The general summary but vaguely expresses the true state of affairs and gives but little idea as to the location. The publication of individual reports is, in my estimation, by odds the best plan if sufficient space can be given to each correspondent, but to do this would require more space than is available in a bulletin of the size now in use. Many of the States contain more than one hundred counties and with several reporters in a county it would be impossible to publish remarks from each in a bulletin of the present size. As one means of overcoming the difficulty and at the same time covering the ground more thoroughly than could be done in a summary, I would suggest that each individual crop be treated under the proper heading similar to what has been done by the New England section. In this way full weight can be given each report as well as a clear idea as to the true condition of each crop. The chief, and I may say the only objection to the publication of reports by counties, lies in the fact that it is impossible in most cases to give an intelligent idea of the crop conditions, owing to the limited space available. The method adopted by some directors of publishing the reports in rotation, I think, is objectionable; it breaks the chain of evidence which should be continuous from week to week during the entire growing season, besides it not infrequently causes dissatisfaction among the reporters who feel slighted to find their reports left out. From my experience I am convinced that it is far better to have from one to two reliable reporters well located in a county than several. Within the limited time between the receipt of the cards and making up the bulletin for publication it is impossible to do justice to more than three hundred reports. I would suggest that the number of correspondents be not more than two to a county, and that as far as possible each county in a State be represented.

It has often occurred to me that there should be certain most favorably located points from which weekly reports of temperature and rainfall should be sent to the section center for use in the compilation of the bulletin. In order to reach the section center in time for publication many of the cards must be mailed on the Saturday before. Between the departure and arrival of the report some sudden and decided change may occur in the weather as well as the condition of crops which can not now be always known by the director. With telegraphic reports it would be possible to publish the normal conditions, together with the departures therefrom, which would afford excellent opportunity for study. There may be some difficulty in securing the desired cooperation at first, but valuable results would soon be realized, and after a short time this trouble would be overcome.

Mr. CLINE. The weekly bulletin is one of our most important publications. I believe our bulletin represents a greater proportion of any one interest in the States than the bulletin of any other State. It represents one-third of the cotton produced in the United States, and of course it is closely watched by the dealers, not only throughout the United States, but throughout the world. The substance of our bulletin is cabled every week to Europe. Now I consider it a very important matter to publish the correspondents' remarks. The general summary will not suffice, because the local merchant is continually advancing money on the crop in different parts of the State and he not only wants the general summary for the entire State but he wants to know what the conditions are at every individual point. We can only give him this from correspondents' remarks. Another thing, the newspapers know what kind of information is valuable to the public, especially the daily press, which is crowded for space. Take the newspapers and ascertain what space they give to your bulletins, and you may judge of the value of the information you are giving in it. The Daily News, published at both Galveston and Dallas, and the Post, published at Houston, publish all our correspondents' remarks, sometimes running as high as three columns. That shows the value they place on this item. I consider the correspondents' remarks one of the most valuable features of the bulletin; that is, to the broker and the producer. I publish these correspondents' remarks by stations, and try to bring them in by rotation in different sections, as far as possible, so as to give them all a chance. It would be impossible to publish the entire list of correspondents for Texas in any one bulletin; it would take one printer three or four days to get it done. But we can take say sixty or seventy-five places well distributed over the cotton-growing portion of the State and give sufficient information to guide both the broker and the producer. I believe I can say nothing further in this connection, but I think we should make an effort to publish correspondents' remarks as far as possible.

Mr. BATE. I consider the weekly climate and crop report the great publication of the Bureau. I am happy to say that during the past year the weekly climate and crop bulletin work has been more highly complimented than ever before. As to the publication of the individual reports, I think that is much more satisfactory to the people who send in the reports, and also much more satisfactory to the public. I always supplement the observers' report by a short summary.

Mr. JENNINGS. The most important part of the bulletin is that devoted to the individual or county reports. I was never so forcibly struck by this as when, a year and a half ago, the usual letter came, requesting a summary of so many words to be sent by such a date, to the Central Office, so that it could be included in the March bulletin. I went down to the Secretary of the State Board of Agriculture, and asked permission to use his reports and get the addresses of his correspondents. "Why," said he, "we have quit. We have no use for any reporters since you have been getting out that bulletin in that way." So I went down to the office of the Kansas Farmer, where for years they had been getting reports from special correspondents, and they too had quit. They considered our report better than anything they had ever had. That shows the value placed on these county reports by the people at home, and to go to work and cut them off is, in my judgment, to cut off the most important part of the bulletin. You know Kansas has the reputation of being plastered all over with mortgages. Well, every big trust company in the east takes these bulletins of ours, and they use them for getting information needed in their line of work, depending very largely on these individual or county reports. There are large wholesale establishments which have men traveling over our State. They want these reports, and they want the county reports. It enables them to judge where best to send their men this year or next year. If they have a dry spell in any part of the country, they don't care to place many orders there. So these county or individual reports are considered in all parts of the country as the most important part of that bulletin.

Mr. McGANN. I think every section director should issue a crop bulletin that he knows will meet the approval of his State. Each State has its own interests; you could not well have New Jersey following the lead of Alabama, or Alabama following New England. Each section director should do the best he can. In New Jersey we want individual reports, and in order to protect themselves from the speculator, the farmers don't want anything to do with the summary. The individual reports are the most valuable part of the bulletin.

Mr. Bauer thought but little credence was placed by chambers of commerce and different commercial bodies, except in a general way, in the individual reports of crop conditions in different sections. He believed it well, however, to publish reports of correspondents, as it encouraged them. He thought more attention should be given to the meteorological features of the bulletin, and particularly to the matter of rainfall, and that we ought, if possible, to provide crop correspondents with rain gauges, so that we would get full and complete rainfall reports.

Mr. Hammon, speaking on the second subject of this topic (No. 14) said that in some States it was absolutely essential to use the telegraph. If he did not use the wire in California for this purpose, he would never get the bulletin out in time to be of any use whatever.

Mr. Chaffee also thought that every section director could use the telegraph to good advantage.

This concluded the afternoon session and the Convention, at about 6 p. m., adjourned to meet at 10 a. m. the following day.

FRIDAY, OCTOBER 14, 1898.

The closing session of the convention was called to order by Professor Abbe at 10 o'clock a. m., October 14th.

TOPIC No. 15.—FROST FIGHTING.

ALEX. G. McADIE, New Orleans, La.

Mr. McADIE. An apology must be made by the writer for presenting a paper which is little more than preliminary in nature. The wish to make known the results of experiences in California, for the benefit of localities where the frost period is not yet over, has prompted this paper, and must be an excuse for such a brief presentation of important features of the problem of frost fighting. No one living in California during the past winter could fail to be impressed with the magnitude of the interests affected by frost. True, there are other critical weather conditions which affect the welfare of the community to a greater degree, such as a steady prevalence of hot north winds in May and early June, burning the grain when it is full of milk, or a deficiency in rainfall during the germinating and growing periods, December to April, so marked that cattle perish for lack of feed and all vegetation suffers. But, speaking generally, the subject uppermost in the mind of the fruit grower from the beginning of December to the end of March is FROST. When one thinks of the vast fruit interests, both citrus and deciduous, centered in this State, and realizes that the toil and expenditure of a year may vanish in a night, he can appreciate with what interest every step in the campaign to free the fruit grower is followed.

Unusual atmospheric conditions prevailed last winter in California.

No better opportunity to test certain theories and propositions connected with frost-protecting methods could be wished for. Moreover, a certain measure of success had rewarded a limited number of orchardists who had followed, in the previous winter, the suggestions of Mr. W. H. Hammon and others, demonstrating the possibility of protecting against frost even in the coldest weather likely to occur in California. The Weather Bureau office at San Francisco for two years lost no opportunity of emphasizing the following points: 1st, that frost could be successfully forecasted; 2d, that fruit growers could be warned in ample time to perfect arrangements for energetic and wide-spread smudging; and, 3d, as a result of the other two, that fruit growers could save the loss due to frosts, hitherto accepted as unavoidable. Valuable articles upon both theory and practice of frost protection were published and the whole matter brought prominently before the public. Many orchardists have experimented and much practical information is the result. At Riverside, the Horticultural Club appointed a committee to secure data showing the relative efficiency according to practical tests of the various protective methods, viz, smudging, moist smudging, steaming, dry heating, screening, flooding, etc. In brief, the results are:

1st. That the temperature of orchards can be materially raised by dry heat.

2d. The radiation of the earth's heat can be materially lessened by moist smudges started early and properly managed.

3d. Raising the dew-point by means of steam producing devices was not successful. (But this conclusion may not apply for localities elsewhere.)

4th. Cloth or mat covering is effective but expensive.

5th. The temperature was invariably higher in old seedling groves, or where tall windbreaks afforded to smaller fruit trees a like protection, than in exposed orchards. A tall well located windbreak is an advantage, but one not properly located may be a disadvantage.

6th. The temperature 20 feet above the ground was 1° to 2° higher than at the surface; at the height of 50 feet the temperature was from 5° to 10° higher than at the surface, when the air was still. When the air was in motion, the difference was slight.

7th. Coal baskets sufficiently numerous proved the most effective protectors. Oil pots make a hotter fire, but the deposit of lampblack upon tree and fruit is objectionable.

The whole report of this committee is of the greatest interest, and should be read by all fruit growers. For orange and lemon growers it is a most valuable paper. Figures showing the cost per acre of effective protection are given.

These experiments were made in the heart of the great citrus belt of southern California. Measures which are of greatest efficiency in this region, however, may not be well adapted to other districts. The protection of citrus fruits also is somewhat different from that required for deciduous fruits, grains, cranberries, and garden truck. To the report of the Riverside Committee we may properly add the following general consideration:

8th. The method of protection having the highest efficiency will not be the same for all localities and conditions. Each grower must determine for himself what method is best suited for his particular farm and crop.

Beginning almost with the first day of December, the season was characterized by frost. In time we shall probably know of some relation between the position of the permanent high-pressure area over the western portion of the country and the prevalence of low temperatures and heavy frosts. The pressure distribution for December is shown on Chart I of the report. The motion of the surface air out from the high area can be best understood by using, in connection with the different charts of pressure conditions, the relief map of southern California. Specific maps preceding frosts are Charts II and III, the former preceding by twenty-four hours the frost of December 3, the latter, the frost of December 20. A general similarity exists in the pressure distribution on both dates. Not every map of this type, however, will be followed by frost. The most important relation yet determined in forecasting frosts for California is one first pointed out, so far as the writer knows, by Mr. W. H. Hammon, namely, that the movement of a wave of falling pressure from Montana or Idaho southward across Utah and westward through southern Nevada and thence into Arizona or southern California, followed by a quick rise, is a good indication of much colder weather in the citrus belt. Given then a circulation of air typical of a frost condition, can we explain the localization of frost as a consequence of air drainage? The cold air is shown to move from the northeast, i. e., from the regions of freezing temperatures to the comparatively warm true citrus belt. Conversely, when the air moves from the warmer sea eastward over the land there is little danger from frost. Indeed, the second law in frost forecasting for California is that a breeze from the south or west will prevent frost in the citrus belt. An example of this was shown on the morning of December 3 at San Bernardino, where at 6 p. m. the temperature was 42°; at midnight, 30°; then a slight wind sprang up from the southwest, and the temperature had risen by 2 a. m. to 36°, and the danger of frost was over.

If we could follow the air as it moves, we should doubtless find a close agreement between the frost belts and certain drainage channels. An attempt to do this has been made. Mr. Frank H. Olmstead, for the Los Angeles Daily Times, surveyed the frost localities in Los Angeles, Riverside, San Bernardino, and Orange counties, and plotted these upon a relief map. The relation between air drainage and frost formation is quite apparent. From all of these investigations the following deductions can be drawn:

1. Where the air was in brisk motion the damage from frost was slight.
2. Stagnant air, such as would exist in low valleys, basins, inclosed patches, etc., favors frost.
3. Cold air draining into a region where there is an ascensional movement may give rise to frost streaks. Hence, large fires are not, as a rule, advantageous, as they simply facilitate the ingress of cold air.

These deductions make it plain that frost is not a haphazard matter, occurring without reference to physical laws and beyond explanation. On the contrary, every seeming contradiction, when carefully studied, will show some natural law at work, and that the results are in accordance therewith.

It would be of the greatest value to determine experimentally what the vertical distribution of temperature is at times of frost. It is known

that the isothermohyps (equal temperature heights) are complicated at night near the ground, because of the inversion of temperature with increase of altitude. It has been found by experiments with kites (Blue Hill Meteorological Observations. Explorations of the Air by means of Kites, pp. 100, 112) during cold waves at Blue Hill, Mass., that there is a fall of temperature with increase of altitude at the adiabatic rate (1° C. for 100 meters) from about 300 meters upward. Below this height it is more rapid. This is said to be the especial characteristic of the cold wave during the day; but the night curve, notwithstanding excessive radiation, is said to show a rapid decrease of temperature from the ground upward. The fall of temperature is not so rapid near the ground in the night as in the day. These departures from the normal rate are full of significance at times of frost. Perchance by their aid we may yet be able to foretell with certainty the coming cold wave, and also find in them clues to improved methods of protection against frost based upon a utilization of the heat already present in the atmosphere, but now lost because of imperfect mixture.

TOPIC No. 16.—AERIAL OBSERVATIONS.

G. B. WURTZ, Pierre, S. Dak., G. HAROLD NOYES, Topeka, Kans., J. C. PIERCEY, North Platte, Nebr.

MR. WURTZ. In describing the results of the aerial observations carried on by the Weather Bureau during the past six months, I must confine myself mainly to the experience of a single station, but I take the liberty of adding a few fragmentary results which I have learned from others.

The work at Pierre was taken up late in the spring of 1898, and, while nominally under my supervision, was directed and conducted entirely by Mr. Orville C. Burrows, assisted by the kite reeler. In the matter of directing special efforts to some particular line of work, or to probing into some partially understood phenomenon, aerial observers were empowered to use their own discretion and inclinations as to methods in this scientific research. These men have done good work, considering the attendant circumstances; the majority of them were employees of but two months' experience as observers when they began the work. This short apprenticeship was devoted principally to the mastery of the mechanical problems incident to flying kites of large dimensions at high altitudes. I dare say that inexperienced men had to be put at this work because more experienced observers could not be spared from other fields; but, for this very reason, it could not be expected that the results of their labors should be startling in their meteorological revelations. That some tangible results are apparent is a great credit to these men, some of whom could not have appreciated the general scope of the meteorological science for which they were attempting, as it were, to blaze new paths to knowledge in the wilderness beyond. Indeed, their position is like that of one inexperienced in woodcraft attempting to survey and bring back an accurate idea of an unknown forest, or like that of a high-school boy trying to diagnose and explain the mysteries of some unknown disease. I say, then, that credit is due these men for obtaining any valuable information whatever by their work. While these results amount only to crude suggestions as to

the paths for more careful research, I feel confident they are worthy of considerate attention.

Perhaps, no more important demonstration has been made than the fact that the apparatus thoroughly fitted for one station is sometimes not adapted to the needs of another. To my mind, the experience at Pierre demonstrated that the first kites supplied were not strong enough for the winds. Even a smaller kite—one of scarcely more than half the surface—has been found too large for use in some of the winds, and many good ascensions have been cut short by the increasing pull on the wire. It is evident that to get the best results, the kites must go up in as many kinds of weather as possible. A lack of wind is an insurmountable difficulty, and strong winds are likewise often beyond the capacity of the present outfit. During the month of September, more observations were lost at Pierre on account of high winds than light ones. Bad weather and electrical currents of high potential have not interfered materially.

One of the difficulties we had to overcome was the breaking of the safety wires from sudden gusts, before very great elevations were attained, when convectional currents were playing an important part in the circulation. When the safety wire breaks under such circumstances, the ability of the kite to lift is so reduced that a good ascension is out of the question.

I invented a device to overcome this trouble from sudden gusts, without permanently changing the inclination of the kite. It was so constructed that at any pull up to some predetermined tension, as say 65 pounds, the angle of the kite would remain the same as normally bridled. After this tension was passed, however, the angle would decrease and thus usually allow the kite to overcome the effect of the gust and again resume the normal angle. If the critical strength of the safety wire was reached with the kite at the lesser angle, then it would break, and the kite would have to continue flying at the lesser angle. A two weeks' trial of this device resulted in no safety wires being broken, while previously the breakage had been nearly one to each ascension.

It has frequently been found that when moderate currents prevailed above and the surface winds were too high to admit of sending up the larger kite, the smaller one would not properly take up the sag in the wire, yet cumulus clouds showed good currents at slightly greater elevations. The trial of a small diamond kite under such conditions showed an increase of 3° in the angle of the kite and also of the wire at the reel, while the pull was almost inappreciably increased. In flying tandems, it is also possible, when conditions are favorable, to increase the surface exposed to the wind, or on the other hand, to take in a portion of the canvas when the pull is too strong. It needs no explanation to the kite-flier to show the advantage of having the lower two or three thousand feet of his wire well up off the ground, the trees, and the surrounding chimney tops. It is a decided advantage too to be able to take off one-fourth of the pull after one-third or one-fourth of the wire is reeled in when the dynamometer exceeds 65 pounds. For these reasons, I am inclined to advocate the use of tandem kites, but only when it is done to help out the first kite or pilot. If one kite will take the instruments above 5,000 feet, that is enough, to be sure, but if it will not, I say put on two, three, or more kites as may be required to make an observation.

In this connection, an appliance for attaching the tandem to the main line without impairing its strength and in such a manner as to be readily removable is a necessary precaution. Several more or less satisfactory devices have been used by those accustomed to fly kites in tandem.

But these mechanical improvements are of little use, unless we find them the means of making valuable discoveries for broadening our knowledge of meteorology and improving our forecasting. Our observations at Pierre apparently developed several "sure signs." They may have been local ones, but I believe they will bear fuller investigation. If they are forerunners of general disturbances, as I hope and believe they are, they will be of great value to the forecaster.

We had been accustomed to seeing a daily weather map at other stations. We received no reports at Pierre but we could not overcome the habit of looking daily for the basis of a reliable forecast, and we found one more reliable in the results of our kite work than in all other data obtainable.

When, at an approximate elevation of 2,500 feet, we found a stronger wind than at the surface, we knew almost certainly that we should have it at the surface before the day was over. Now, it is true that wind velocities depend to a considerable extent upon the barometer changes, and the steepness of the gradients, but there are times in the Dakotas when quite marked depressions pass without much wind, while at others some of the most disagreeable dust-storms occur when least expected. It is noticed that when the barometer leaves us in doubt, the kite reveals the truth.

The wind velocity at a considerable elevation would also show regularly a more marked variation in the velocity from morning to noon than was exhibited at the surface. Sometimes this variation would be a decrease so great that the kites would not remain up, and sometimes it would be an increase. This increase or decrease occurred as regularly as the sun rose from horizon to zenith, but I could not satisfactorily connect it with other phenomena. There appeared to be no means by which could be foretold the way the change would occur. Also, when the conditions above were not of the extraordinary type that later showed themselves at the surface, there appeared to be no close association between the changes of wind velocity at the ground and in the higher air. If this were better understood, I surmise that it would exhibit some interesting facts relative to the effects of insolation upon the cyclonic circulation.

We noticed early in the summer that sometimes there were inversions of temperature through the first 2,500 feet of the atmosphere and slight decrease of temperature in the continuation of the ascent. Sometimes these inversions were marked—the temperature 2,500 feet above the ground being from 15° to 18° higher than at the surface. These occurrences were invariably followed by a hot wave, and the heat usually became high at the ground by the middle of the same afternoon, and surely so, by that night or the next morning.

Another observation was that when all the other conditions are indicating rain, no rain, or scarcely any, falls when there is even a slight upward tendency to the thermograph trace in passing through this layer of 2,500 feet.

Conditions were not favorable during the summer for noting the peculiarities of the thermograph trace with reference to cold waves.

The changes to cooler weather approximate more nearly a return to normal temperature, or only slightly below. What the winter observations will reveal in regard to the advance of cold waves, I am unable to anticipate, but I do look for some valuable results.

Some characteristics of Dakota climate might well be taken into consideration in this discussion. Often rainy conditions are apparent in the atmosphere, but with the rain clouds floating at much more than an average elevation. Not infrequently rain is plainly visible falling in a heavy shower from cumulo-nimbus as they pass across the country, yet evaporating before it reaches the ground. The falling rain appears like a vast fringe, well-defined at the base of the cloud and depending to some distance below it, but growing lighter, and toward the ground disappearing in mist. I know this is no optical illusion, for I have made careful observations of such clouds as they approached, passed directly overhead, and on to the other side with the same appearance still remaining. When the cloud is directly overhead, its form is hazy and indistinct, and its distance very hard to judge. It may be said that at this time one feels that he could almost touch it, and at the same time is uncertain but that it may be very far away. These clouds always come from the west. And now to seek the cause of this phenomenon. The atmosphere, so laden with moisture that rain must occur, and yet so dry that the showers evaporate before reaching the ground, is indeed a strange condition. One hundred and eighty miles to the west of Pierre and the Missouri Valley are the Black Hills, and when westerly winds, moisture laden, pass over this range, the entire current is deflected upward from 4,000 to 7,000 feet above the sea. The Missouri River is some 1,400 feet above the sea. Midway between the Missouri and James rivers, therefore, to the eastward of Pierre, there is higher ground, which slopes gently toward the two rivers. Eastward of this high ridge there is considerably more rainfall, and it appears quite plausible to me that the upper main current of air flows some 2,500 feet above the earth at Pierre, while the underlying air remains in this basin or comes from some other source. May it not be that some of the cross currents that sometimes give us trouble with our kites at an elevation of about 2,500 feet above Pierre are the eddies set up between these two layers of the atmosphere where they come in contact? May it not be that at this height we shall find the storms nearly continuous? Whereas, the surface observations make it appear that they are broken up by their passage over the mountains and their intensity decreased thereby. This hypothesis should, I believe, be taken into consideration in studying the causes of the foregoing phenomena. Intelligent handling will make these kite observations of value to the forecaster, but to do this they must study with that same delicacy of perception that the good physician does the symptoms of his patient.

Our forecasting has now reached a stage where improvement must be made, not in the ascertainment and recording of new elements or meteorological conditions, but in a more delicate and skillful diagnosis of those we now consider on our charts. An improvement of 5 per cent in the percentages of verifications means the elimination of nearly one-third of the errors.

Mr. NOYES. On the 27th of April, 1898, the first ascension of the

Weather Bureau kite was made at Topeka, Kans., and since then ascensions have been made continually.

A discussion of the results obtained at one station must necessarily be limited; it can, however, be carried on with a degree of profit, confining it to those points which are open.

In considering aerial observations, one of the first noticeable features is the action of the kite and the disclosures it makes of the wind's movements. On the ascension of a kite in a steady surface wind of 12 or more miles per hour, it is noticeable that the kite passes through a stratum of wind of very perceptibly greater velocity than that at the surface and than that in the stratum above. Now it is known that the obstructions at the earth's surface will retard the forward movement of the wind. But what prevents as great a velocity of wind above this maximum zone as the wind slides down the gradient? Again, this zone of maximum velocity is not always present. Sometimes, and this is usually in the early morning, the kite shows its presence during the ascent, and its absence during the descent. Occasionally the phenomenon is reversed, or even does not show at all.

As to the *direction* of the winds, a few figures are of interest. Southerly winds have prevailed in 80 per cent of the ascensions, and westerlies in 57 per cent. This gives more than 100 per cent because the southwest winds are counted as both southerly and westerly. Apparently these southwest winds are passing down the gradients into the areas of low barometer which are continually passing over the Great Lakes eastward down the St. Lawrence Valley in the usual form of the cyclonic whirl. Oftentimes the anticyclonic areas, with light winds, will remain for an extended period in one vicinity, thereby preventing a kite ascension. Cool, cloudy days are likely to prevent kite ascensions. The clouds will show a rapid movement, but the vertical convectional currents are so slight, due to the presence of the cloud cover, that only occasionally is the wind strong enough to lift the kite. At this station, it is not often that the surface wind varies, in any direction, to any considerable extent from that above. On one occasion, however, the surface wind was northeast and the kite was in a south wind at an elevation of 3,500 feet. This ascension also displayed a very singular phenomenon which, while not meteorological, was of peculiar interest. On reeling the kite in, at intervals of a few feet on the wire, spider webs were found, and in some cases on the webs were very small spiders. While the kite line was extending to windward, one could see the webs hanging therefrom like a fringe. As the webs extended the full length of the line, they must have been borne as well in the northeast surface wind as in the south wind 3,000 feet up. The sky at the time was cloudy. No webs were found on the kite, and none were seen caught on the grass, trees or bushes. Perhaps these facts will interest entomologists.

When an ascension is made within an area of low barometer the humidity is usually recorded high, and the lowest humidities are recorded during a high barometer. The aerial humidity preceding rain has invariably been high.

Frequently an early morning ascension shows an inverted gradient of temperature. That is, up to 900 feet or 1,500 feet perhaps, the temperature rises higher than at the earth's surface, and then above

that height commences to fall again. As the sun rises higher and convectional currents move upward and downward this inversion ceases, as shown on the descent of the kite. Toward the middle of the afternoon the normal gradient is shown by an ascent, but if the descent is made during, or especially after, the twilight period then an inversion of the gradient is shown.

The electricity which ever descends the wire is strangely interesting. Sometimes five hours after thunder has been heard and the kite is 4,500 feet up, with cloudy sky, there will not be the least sign of electricity, and at another time, with the kite 1,000 feet high, and the sky nearly or wholly clear, the shock from the wire is far too unpleasant to take. Perhaps my opinion on electric shocks is not impartial. Those who saw the article in the *Monthly Weather Review* for April, 1898, will perhaps remember the accidents caused by electricity heating and burning the kite wire. It is about one of these accidents I wish now to speak. There seemed, on May 31, 1898, to be a thunderstorm approaching; no lightning was visible or thunder audible, yet my reeler and I commenced to pull in the kite. When the kite was still 3,000 feet up, at the end of 5,000 feet of wire, a bolt from the clouds was seen, by others, to hit the kite. We stopped reeling; we had to. I have been nearly in front of a 6-inch naval rifle at its discharge, and its noise was very mild compared to the report which we heard at the reel. We were stunned for a brief period and the wire was ruined by the discharge. Fortunately, the kite reeler was wearing rubber overshoes, but I was not, and in consequence got a burn on the sole of my foot; this, however, was of small import in view of the experience gained. The kite fell 3,000 feet, breaking one stick. Several really ludicrous events have occurred when the kite has behaved badly. Sometimes the operators get knocked down and dragged about by the kite in attempting to land it, while the urchins, at a distance, shout humiliating taunts.

It would appear, however, that the aerial observations are not, as a whole, of continuous value, because of their great irregularity. It is not often that the kites go up at 8:00 a. m., and then it is less often that synchronous observations can be made at each of the kite stations because of atmospheric conditions. One requisite is some more sensitive form of kite meteorograph; another is some form of captive balloon that can ascend when rain or lack of wind prevents the kite from going up; but, with the appliances available, it is certainly a most creditable accomplishment for the Weather Bureau to have made as much as it has out of the aerial investigation of the free air.

Mr. PIERCY. My duties in connection with aerial observations at North Platte, Nebr., have only been of a cursory nature, but my interest in the work has prompted me give it some study. The practical work is performed by an aerial observer, so I can only deal with this subject in a general way. Aerial observations were first begun at North Platte, in April, 1898, and have continued ever since. By careful observance I have noticed that an unusual amount of humidity, electricity, and moderately low temperature in the upper air strata frequently indicate precipitation within the next twenty-four to thirty-six hours. An absence of these conditions foretells dry and fair weather.

A high temperature in the upper atmosphere is invariably the forerunner of a warm wave on the earth's surface, which usually occurs within twenty-four hour. While I have had no experience in aerial work during the winter season, I believe that it will be of value in forecasting cold waves.

TOPIC No. 17.—SHOULD NOT A BOOK PROVIDING FOR A PERMANENT RECORD OF METEOROLOGICAL OBSERVATIONS FOR A PROLONGED PERIOD BE FURNISHED TO THE SECTION CENTERS FOR THEIR USE AND FOR VOLUNTARY STATIONS ?

G. A. LOVELAND, Lincoln, Nebr., and J. W. BAUER, Columbia, S. C.

Mr. LOVELAND. The need of some method of filing, in compact form, at the section center, the monthly values of the more important meteorological data recorded by the voluntary observers has been felt in Nebraska for a long time. The records can not be used in a study of the climatology of the State to the best advantage, if at all, until all the record of each station has been collected in such manner that it can be viewed as a whole and the essential facts obtained quickly and easily.

To answer the many questions constantly being asked this office regarding both the climatology and the weather during specific periods of the past in various parts of the State, it was found early in the history of this work in Nebraska to be a saving of time to thus arrange data. It seems to me there can be no question as to the advisability of some method of arranging the records by stations; it is an absolute necessity. The only questions it seems to me are: What is the best method, and what data should be entered? Two methods have been tried in Nebraska and each had its disadvantages. One is placing the record in a large unwieldy book; the other, placing each element, as temperature or precipitation for each station for the use of the station on a loose sheet of paper, and then arranging these sheets on a file in the alphabetical order of the stations. I am inclined to prefer the separate sheets, but think a thin cardboard should be used as the paper becomes torn and wears out so easily.

The cards could be printed alike for all the elements, and the nature of the data entered at the top of each card when the data was entered. Holes should be punched on the side for filing, and the cards could then be turned like the leaves of a book. A file case should be furnished to protect the cards like the covers of a book. The great advantage of this system is that the order of arrangement of the stations can be changed at will without trouble or delay. If the records of a district or a few stations are being studied they can be separated from the rest of the file to a great advantage in the work as well as a saving of time.

The data to be entered would depend largely upon the location of the section and the use made of the records, and somewhat upon the force at the section center available to do the clerical work required to keep the records copied. With the card system the amount of data thus kept tabulated could be left to the director of the section. I should not think it desirable to enter daily records at all but only monthly values.

The cards would be used to supplement the regular monthly report

and not to take its place, and one set of these cards should be furnished to each voluntary observer.

Mr. BAUER. The question presupposes a doubt as to the suitability of the present Form No. 1009—Met'l for purposes of a permanent record. Form No. 1009—Met'l is well devised for transmitting to the section centers and to the Central Office the reports of voluntary observers, but owing to the flimsiness of the paper and the fact that the leaves for each month are necessarily loose and separate, the form is not suitable for permanent record, either at the section center or at the home of the voluntary observer, few of whom are equipped with desk room for filing such papers, or even the crudest facilities for binding them in annual volumes, and hence their liability to be lost or inadvertently destroyed. A suitably arranged book would avoid this, and by showing the voluntary observers that their reports are deemed of sufficient importance to be preserved in permanent form, would encourage accuracy and the continuity of their records.

Such a book, strongly bound, should provide space for notes on the more important meteorological events that are but inadequately described by figures alone; the spaces for the tabular data should be so arranged as to afford facilities for easy comparison by months; when the book is filled, the means of the footings would represent average conditions. By such an arrangement, a comparatively small book could be made to serve for many years.

It might be well to have a separate book for each station for the use of the section center, but this could be made much smaller by omitting all blank spaces for remarks, etc. It is true, that to keep such a book for each voluntary observing station at the section center would involve much additional labor in copying, but the results would, in my opinion, justify the additional time and labor required.

This office has recently been requested by several voluntary observers to supply missing reports which had been mislaid or lost. Such requests have a twofold signification: First, that voluntary observers are desirous of having a complete record of their observations, and second, the unfitness of the present Form No. 1009 for purposes of a permanent record on account of liability to be lost.

Without hesitation or doubt, I therefore declare myself heartily in favor of providing books in duplicate, one copy for the section center and the other to be issued to voluntary observers as their private property, for permanent record of voluntary observer's meteorological observations.

Mr. LINNEY. A brief inspection of the sample book for a permanent record of the voluntary observations, exhibited by Mr. James Berry, Chief of the Climate and Crop Division, would lead me to state that it might be an excellent thing for issue to such of our voluntary observers as desire something for permanent record purposes, but I would suggest that it should not be made requisite to the establishment or continuance of, any voluntary station, nor should it be considered a part of the equipment of all stations. It should be borne in mind that in the hands of the average voluntary observer the use of such a book will cause many faults to arise. Thus, if the book is made the permanent and original record many errors will

creep in by copying to the Forms No. 1009, and much delay will be sure to result in forwarding forms. With probably 80 per cent of the observers many errors will regularly be made in attempting to find sums, means, highest, lowest, etc., and the number of errors which will thus arise, making correction necessary, will seriously impair the value and appearance of the book as a permanent record in the hands of the voluntary observer.

As to its usefulness, or value, at the section center I can not assent for several reasons:

First. It is wholly impracticable for the directors, with the present office help, to attempt to make the copies required, and even if the necessary help were provided the results would not justify the outlay of time, money, or effort, for once you have the copy in the book you have nothing more than you had on the tissue Form No. 1009, and it is not original.

Second. The present plan of tissue duplicates furnishes an accurate and good permanent record, easy to handle, compact, and, if properly filed, accessible, while they only require computation and summarizing to be available for current and future use.

Third. The monthly publication of each section summarizes the reports of the section as a whole and individually, thus covering all of the ground given in the proposed book, and these, if bound in yearly or bi-yearly volumes, would become a neat and valuable permanent record to supplement the retained Forms No. 1009.

Fourth (by way of suggestion and recommendation). A file case somewhat after the plan of that in use at the Chicago office, a box being provided for each county in the section, would cost but little more than the proposed books, which must be specially made, and the reports could then be filed easily and safely, and for future use would be at hand at any moment.

Mr. PALMER. Relative to the book for permanent record of voluntary observer's report, spoken of and shown at Omaha, I have the honor to make the following report:

Many voluntary observers would undoubtedly like such a book, and it would be advisable to place one at their disposal. Most of them, I believe, find their tissue reports, properly filed away with the section publications, sufficient for their use.

A proper file case for filing all reports from each station together seems to me much preferable to the book shown. In this way records from each station can be readily referred to. The copying of these monthly reports, especially the maximum and minimum temperatures and the daily rainfall, means a large amount of additional labor at the section centers.

I believe that the page in the book devoted to the general summary should be issued for the section centers, but in a slightly different form, ruled so as to have room for "sums to include" and "means to include" succeeding years. Then the section centers could keep all means for substations up to date, and also furnish material for the "climatological addenda" such as is published by the Ohio and Indiana sections.

I have been working up the records at my substations, including only temperature and precipitation, and I should have been glad to have had blanks, as mentioned above, for this work.

TOPIC No. 18.—PAPER: ATMOSPHERIC MOISTURE AND ARTIFICIAL HEATING.

W. M. WILSON, Milwaukee, Wis.

Mr. WILSON. The importance of aqueous vapor as a constituent of our atmosphere was not exaggerated by Tyndall, when he startled the scientific world by the announcement that "The removal, for a single summer night, of the aqueous vapor from the atmosphere which covers England would be attended by the destruction of every plant which a freezing temperature could kill."

For a long time humidity, relative or absolute, has taken its proper place among the principal meteorological elements, and every meteorological service in the world maintains a series of observations of atmospheric moisture with the same care as that bestowed upon temperatures, barometric pressure, or rainfall. The intimate relation existing between the aqueous vapor of the atmosphere and its precipitation in the form of rain or snow has inspired practical meteorologists with the hope that in the study of this element might be found the solution of the problem of rainfall, and possibly lead to more accurate results in forecasting its occurrence. But while the relation existing between the various forms of water is very close, a knowledge of the exact conditions which exist, in sufficient force to account for a downpour of rain, has eluded our grasp, and the results of the study of this element, so far as practical weather forecasts are concerned, have been principally negative.

From a medical point of view, however, the importance of the relative evaporative power of the atmosphere, in estimating the peculiarities of special climates and their effects upon the human organism, must be evident to all who are familiar with the physiological functions of the skin and lungs, and of the mucous membranes of the entire respiratory tract. Indeed, according to Dr. Albert Buck:

For certain classes of invalids the prevailing humidity at a given place is a matter of more consequence than the temperature; more important than the mean temperature—nay, in the opinion of some authorities, a matter of more import than is the variability of temperature, be the variations of the latter never so frequent, never so great, and never so sudden and sharp in their onset.

The connection which subsists between the humidity of the atmosphere and its capacity for absorbing moisture from bodies, both animate and inanimate, with which it is in contact, is a connection of the closest possible description, but it is a deplorable fact that medical literature is almost entirely lacking in a scientific explanation of the effect of the different degrees of humidity upon the animal economy. There is abundance of empirical evidence of the efficacy of the conditions prevailing in the different portions of the world for the cure of catarrhal and pulmonary troubles, but whether the improvement which not infrequently follows a residence in Colorado or New Mexico is to be accounted for by the dryness of the climate, as is the popular impression, the elevation above sea level, the abundant sunshine, the new surroundings, or the outdoor life, or whether it is the result of a combination of all, physicians are unable to say with any degree of certainty. It is, however, generally admitted that while aridity and elevation may play an important part in the curative process, the efficiency of the climate in this respect does not depend on these elements alone, as equally good results are obtained from a residence at Torquay or Falmouth, on the south of England, which are

among the most humid climates on the globe, and are elevated only a few feet above the level of the sea. Many believe that the results, so far as humidity is involved, which follow a residence at any place possessing special climatic conditions are not so much due to the dryness or saturation of the atmosphere as to the comparative freedom from sudden or extreme changes in humidity, incident either to the natural climate or to the comparatively small range between the humidity prevailing inside the dwellings and that of the outside air.

We will assume that during the winter months the normal relative humidity over the more populous portions of the United States, especially east of the Missouri and north of the Ohio rivers, is 72 per cent, and that the average diurnal range is from 60 per cent to 85 per cent, which, it is believed, fairly represents the conditions prevailing over the area named.

For the purpose of obtaining data upon which to base a comparison between the average external humidity and the prevailing conditions with respect to moisture found in business offices and living rooms, observations were carried on during the past winter in buildings heated by steam, hot water, and hot air, and it was found that the average relative humidity from steam and hot water heating, with an average air temperature of 72°, was 28 per cent, while from furnace heating it was as low as 24 per cent. Dr. Albert Barnes, of Boston, found that the relative humidity in his office building, with an air temperature of 72° was 31 per cent, while Mr. Henry, in investigating the relative humidity in the Weather Bureau building at Washington, during March, 1896, found that, with an air temperature of 72°, the relative humidity was 32 per cent. From these observations, it is safe to assume that the average relative humidity in dwellings and offices, during that portion of the year which requires artificial heating, is about 30 per cent, or about 42 per cent less than the average outside humidity and drier than the driest climate known.

The evaporative power of the air at a relative humidity of 30 per cent is very great, and when the tissues and delicate membranes of the respiratory tract are subjected to this drying process, a corresponding increase of work is placed upon the mucous glands in order to keep the membranes in proper physiological condition, so that Nature, in her effort to compensate for the lack of moisture in the air, is obliged to increase the functional activity of the glands, and this increase of activity and the frequent unnatural stimulation, induced by the changing conditions of humidity from the moisture-laden air outside to the arid atmosphere within our dwellings, finally results in an enlargement of the gland tissues, on the same principle that constant exercise increases the size of any part of the animal organism. Not only do the glands become enlarged, but the membrane itself becomes thickened and harsh, and, sooner or later, the surface is prepared for the reception of the germs of disease which tend to develop under exposure to the constantly changing percentage of humidity.

If the limitations of this paper allowed, it might be interesting to notice some remarkable cases which have come under observation where catarrhal troubles have been relieved and apparently cured by simply introducing sufficient moisture into the air to bring the conditions to something near the normal.

The economic side of the question is equally interesting, and has

the special attraction of being more nearly capable of a mathematical demonstration. In a room in which the temperature is 72° , with a relative humidity of 30 per cent, the temperature of the wet bulb is 54.5° . If a room with a sensible temperature of 54.5° is considered comfortable—and there is abundance of evidence to show that the wet-bulb thermometer does not vary greatly from the sensible temperature under ordinary conditions—the same result can be attained by heating to only 60° and supplying sufficient moisture to raise the humidity to 70 per cent, which still conforms very closely to the normal condition of the outside air, so far as moisture is concerned. It would probably be impracticable to maintain uniformly a relative humidity of 70 per cent, especially with a low outside temperature, as the condensation upon the windows would be undesirable; but by heating to 65° the relative humidity could be held at 50 per cent without any ill effects, except possibly on extremely cold days.

While no very accurate information is at hand as to the cost of heating at different temperatures, competent engineers estimate that about 25 per cent of the cost of heating is expended in raising the temperature from 60° to 70° . If this be correct—and it is the best information obtainable at the present time—one-fourth of the cost of heating could be saved by holding the temperature at 60° and raising the humidity to 70 per cent, still maintaining a wet-bulb temperature of 54.5° , the same as that obtained by heating to 72° under ordinary conditions. But to be conservative and avoid the possibility of any unpleasant results from condensation, our dwellings could be heated to 65° with a relative humidity of 50 per cent, and still save $12\frac{1}{2}$ per cent over the present cost. A practical test was made on a small scale during the past winter with a view to determining a comfortable sensible temperature and the possibility of maintaining the humidity at a constant percentage. A valve controlled by an electric current was attached to a steam radiator and the electric contact made through an ordinary hair hygrometer. By this means it was possible to steadily maintain the relative humidity at any point desired, but owing to lack of means of controlling the temperature, the experiment fell short of determining the exact temperature and humidity at which the most comfortable conditions prevailed. The recognition of the need of a larger quantity of moisture in dwellings heated by artificial means is not new, but the mechanical difficulties encountered in automatically introducing the moisture in sufficient quantities to accomplish the desired result, or of controlling the amount introduced, has largely deterred practical research in this direction. But it is hoped that these difficulties will be overcome, and at no distant day a humidifier will be as necessary an adjunct to every first-class heating plant as a temperature regulator is at the present time.

TOPIC No. 19.—SHOULD NOT A BOOK BE PROVIDED SUITABLE FOR KEEPING RECORD OF THE ISSUE OF INSTRUMENTS AND FLAGS TO VOLUNTARY OBSERVERS?

R. G. ALLEN, Ithaca, N. Y., and B. H. BROWSON, Bismarck, N. Dak.

Mr. ALLEN. In answer to this question I would say that such a book would be very useful and of much benefit in keeping a correct and

easily accessible record of instruments and flags loaned to voluntary observers, but, in my opinion, a card record would better serve the purposes, would always present a neater appearance, and would be more satisfactory than the book record. This card system would require for each substation a small sized card, with a suitable heading showing blank spaces for the name of station, name of observer, date of establishment, latitude, longitude, and elevation. Just below this heading I would suggest that spaces be provided for the different instruments usually furnished voluntary stations and also the different kinds of flags. With this card method, when a station is discontinued, the card for that station should be removed from the file. When a station is established a card showing the name and equipment could be placed in its alphabetical order. This method would insure a neat, easily accessible, and satisfactory record.

In using a bound book more or less changing is necessary when a station is discontinued or an instrument broken or returned for any cause, and this detracts from the neatness of the record.

I have no doubt but that a book for keeping record of instruments and flags will be valuable and convenient but in my opinion the card record more so.

Mr. BRONSON. Mr. Chairman, in my opinion such a book should be provided. I have kept one, showing kind and the number of all instruments received and issued to voluntary observers, for the past five years, and have found it very convenient.

TOPIC No. 20.—ARE CHANGES IN THE PRESENT FORMS (1063 AND 1064) FOR REPORTING WEEKLY CLIMATE AND CROP CONDITIONS ADVISABLE?

. CHARLES E. LINNEY, Chicago, Ill., and A. J. MITCHELL, Jacksonville, Fla.

Mr. LINNEY. I find very little use for the special report card (Form No. 1064), because my observers and correspondents are usually in advance of requests for matter. The large number which I have makes it possible for me to get from the cards of any week more information than I can possibly use, and generally in advance of the time when it is really pertinent information; thus the possibility of the first frost in the fall is usually anticipated from one to two weeks before the usual request from Washington; so with other things; and I therefore find very little use for the form. It is all right, however, when occasions arise for its use, and in its present form answers every purpose.

Mr. MITCHELL. At the Indianapolis Convention I suggested the propriety of making Form No. 1053 conform to the size of the ordinary postal card, the object of the change being to reduce the possibility of mutilation which frequently occurs in transit. With the reduced size the card will be of ample dimensions to contain all necessary facts regarding condition of crops and effect of weather on same. In fact, the change would emphasize the necessity for succinct statements and brevity by crop correspondents, which count for a great deal in compiling a summary for the State. So far as the Florida section is concerned, Form No. 1054 answers all requirements.

TOPIC No. 21.—SHOULD COMPENSATION BE ALLOWED PERSONS, NOT IN THE EMPLOY OF THE BUREAU, WHILE LEARNING STATION DUTIES TO ENABLE THEM TO PROPERLY PERFORM SUCH DUTIES IN CASES OF EMERGENCY?

DAVID CUTHBERTSON, Buffalo, N. Y., and G. E. FRANKLIN, Los Angeles, Cal.

MR. CUTHBERTSON. The Weather Bureau of the United States Government was organized to meet the unforeseen; it has always aimed to be prepared for any emergency in order to prevent the interruption of its work in any of its branches, since otherwise irreparable loss to many communities may result.

One of the principal things to be provided for is the proper performance of station duties when we have left but one or two men at a station. To enable us, therefore, to be in readiness to meet any crisis, and keep the work going on with regularity, the question has arisen, whether we shall compensate the substitute while he is being instructed in station duties so as to be ready to act in the event of an emergency? As we are willing to pay for the work when the emergency arises, I contend that by all means it is the part of the Government to allow reasonable compensation to a competent person while under instruction.

In my opinion a young man attending a high or normal school or college could be instructed during the afternoons of school days, and on Saturdays could be given practical work on routine duties of a station. This would not interfere with his scholastic duties, and, being an attendant at school or college, having no other remunerative position, he could always be relied upon to render his services as soon as required; when he leaves school and enters his regular vocation then another such young man could take his place.

I am thoroughly convinced that as we expect the person to fill an emergency he should be suitably paid for the time he devotes to the Government in order to learn his prospective duties. At large stations, such as Buffalo, an emergency can not well occur without being successfully met, as the important duties of an observer can always be taken up by the map distributor, and the latter's duties performed by a hired messenger.

MR. FRANKLIN. It is well recognized that at a one-man station it is necessary to have an experienced person to continue the work, at least the meteorological portion, in order to maintain the continuity of the records in case of the unavoidable absence or the disability of the official in charge.

While the regulations of the Service direct that provision should be made to obtain the services of some one for such cases, yet at present no compensation is allowed for training a man for the duties expected of him, and the difficulty of obtaining some one who is willing, without remuneration, to spend time learning station work, with a remote possibility of employment, will, I think, be well recognized by those who have had experience in the matter.

There are stations where it is possible to secure the services of an ex-official of the Bureau, or those of a voluntary observer who is sufficiently familiar with station work to assume charge in emergency cases. This, I think, is an exception and not the rule, so it will be found necessary to train some one as an emergency assistant.

It requires time and experience to obtain the knowledge necessary

to perform the various duties of a Weather Bureau office, and while there may be young men who would give their time and attention to obtain such knowledge without a desire for compensation, such instances have not come to the writer's attention; on the contrary, compensation has been expected, because it has been found necessary to spend considerable time at the station, which otherwise would be given to some line of business that afforded a pecuniary return. Moreover, those who are obtained for such emergency services are usually persons of limited means who can ill afford to give the Government gratuitous service in learning prospective duties.

It is, therefore, the opinion of the writer that some system of remunerating emergency men while under instruction could be adopted with benefit to the service. A well informed man would then be at hand when required, and the station work would be continued without break or lapse, particularly in the meteorological portion.

Mr. Townsend of Philadelphia was given the floor to explain his self-registering rain gauge. The chair appointed, as a committee to confer with Mr. Townsend and report upon the gauge, Messrs. McGann, Walz, and J. W. Smith, of Boston.

Mr. Sims obtained permission to exhibit a simple frame for use in furnishing advance information. The chair appointed as committee to examine and report on the apparatus, Messrs. Townsend, Loveland, and Outram.

Mr. Bate moved—

That the Convention of Weather Bureau Officials tender their especial and grateful acknowledgments to the Commercial Club of Omaha for the hospitable courtesies they have so generously extended in placing their elegant and commodious rooms at the disposal of the Convention for its sessions.

This was adopted, and the Secretary directed to send a copy to the Commercial Club.

Mr. McGann moved—

That the thanks of this Convention be extended to Mr. James Berry, Dr. Cline, and the other members of the reception committee for the very excellent arrangements made for us during this Convention.

Seconded, and unanimously adopted.

Professor Hazen moved—

That it is the sense of this meeting that we have profited greatly by this Convention and that it would be a good thing for us to meet annually.

Mr. Hammon agreed heartily with the first part of this resolution. He pointed out, however, that the expense of a trip from the Pacific coast was too great to allow of attending conventions oftener than once in three to five years. He thought Congress would look upon a reasonable thing to pay part of the expense of one of these
ations.

Professor Moore said he would ask from Congress authority and an appropriation to pay part of the expenses of the Convention. Professor Hazen's motion was adopted.

Some expression of opinion arose as to the time and place of the next meeting.

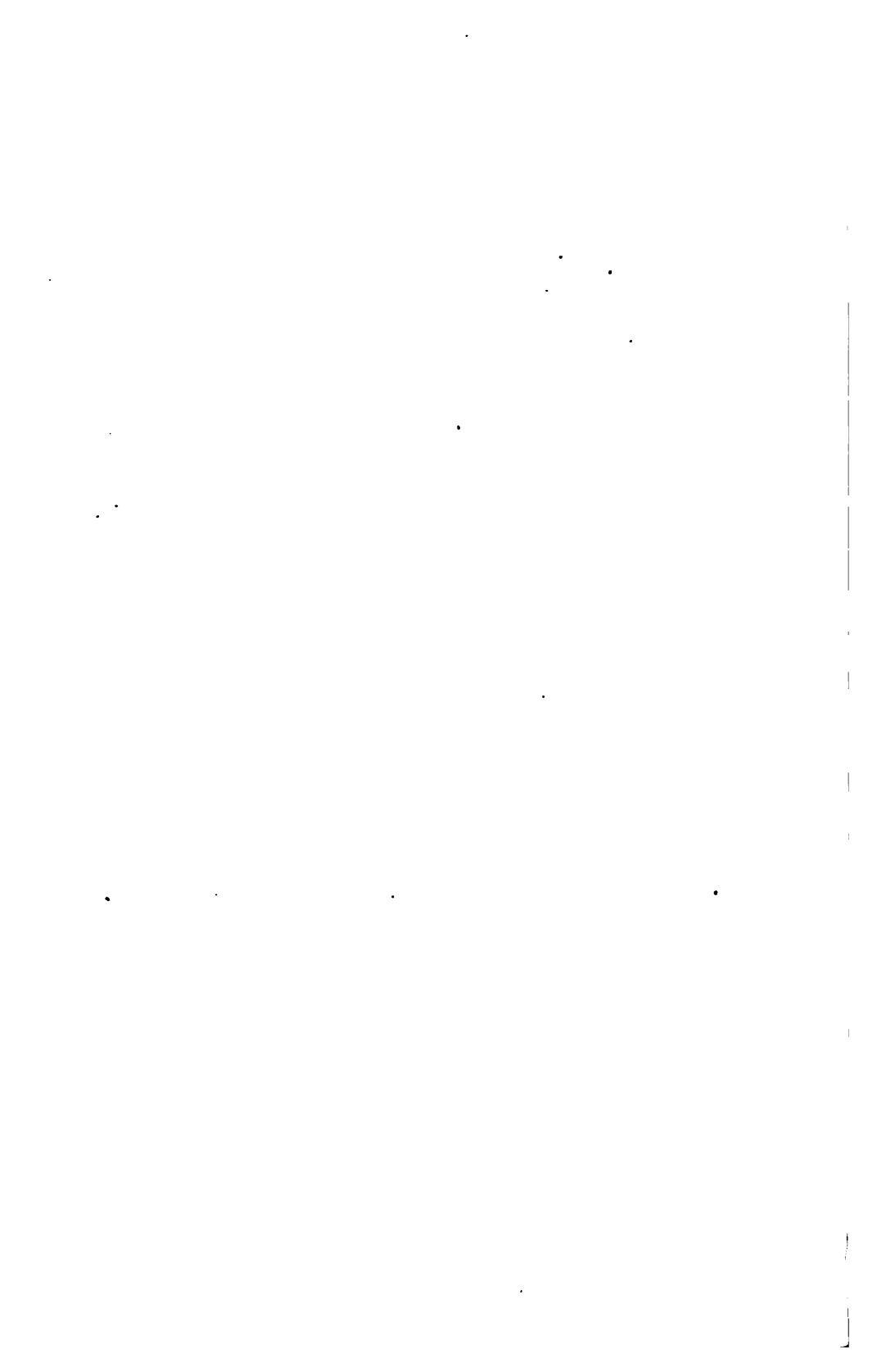
Mr. Pindell and Mr. Bate spoke for Chattanooga, Tenn.; Mr. Hammon, for San Francisco, Cal.; Mr. Pague, for Portland, Oreg.; Mr. Cline, for Galveston, Tex.; Mr. Conger, for Detroit, Mich.; and Mr. Mitchell, for Jacksonville, Fla. No vote was taken, and this matter is entirely in the hands of the Chief of the Weather Bureau.

PROFESSOR MOORE. It is a matter for congratulation that we have had the advantages of this Convention and of the enjoyable, sociable time of last night [referring to a banquet attended by the members of the Convention and their guests]. The utmost decorum has been manifested by all present. We enjoyed ourselves, we had our fun, but we were temperate, and no man lost sight of the fact that he was a gentleman. It is a source of congratulation that this was the case. Now, it is probable that the presiding officer derives more benefit from such a convention as this than the individual members. He gets here what he could not get by many years of official correspondence—that close touch and affinity with the officials cooperating with him in this great institution that enables him to act intelligently and for the best interests of the public service. I feel, as I go away from here to-day, that I have acquired a fund of information from the very best sources that will aid me and guide me during the next year or two in my executive functions at Washington.

Furthermore, this Convention has enabled many deserving men in the service to come forward and present papers to show what they can do. It is a sort of forum in which they can be heard, and it is of great assistance to the head of the Bureau to be able here to see and meet with these workers, that when it comes to the selection, which is vested in him, of officers to go forward to higher stations, the associations here formed and the opportunities for judging of the capacity and merits of our officials are sure to be of great assistance and render him less liable to err.

Gentlemen, this meeting is adjourned.

As previously stated, it was not possible to read in full before the Convention many of the papers contained in the program, among which are those given in the following appendix.



APPENDIX.

PROFESSOR MARVIN'S WEIGHING RAIN AND SNOW GAUGE.

W. W. CARLISLE, Minneapolis, Minn.

The city engineer of Minneapolis, desiring to ascertain the rate of excessive rainfall, expecting to use the data in determining the proper sewer capacity to be allowed in the estimates for sewer construction for the different sections of the city, purchased one of Professor Marvin's weighing rain and snow gauges. After the instrument had been given a reasonable trial, the chief engineer of the sewer department declared himself unsatisfied with its record. Having obtained control of the gauge I have made a careful study of its mechanism, thoroughly investigating it in detail, perfecting its arrangement and removing its defects whenever, by experiment or by observations of its behavior during storms, they were made apparent. I have finally succeeded in making it very reliable, and by introducing into its electrical circuit an instrument which I have called a "controller," it is compelled to produce a record which shows faithfully every increase or decrease of the rate of fall and to register within four seconds of the exact time when the first thousandth of an inch fell into the receiver, with the same degree of accuracy for every succeeding thousandth, including the last. It will register snow equally as well as rain while the wind, formerly so troublesome, makes absolutely no impression whatever upon the record.

While the instrument, at least the one furnished this city, embodies most of the essentials of a perfect mechanism, yet some details of the design seem not to have been fully carried out by the maker, leaving the instrument in an unfinished condition fatal to perfect action. In delicate instruments, and particularly electrical devices intended for outdoor use, every detail must be looked into and every safeguard thrown around it. An imperfect machine naturally must be unreliable and inaccurate.

The scales of the gauge are protected by a hood manufactured from sheet iron, with a hole roughly cut in one side, which is closed by a door also constructed of sheet iron. It is obvious that a sheet iron door, closed against a frame of the same material, can not be shut air tight or even close enough to keep out the rain. The hood has a rectangular base, that shape being retained by means of a wire placed in the hood in a manner identical with the way in which a tinner finishes the top of a tin pail. It is, of course, physically impossible for the base so constructed to fit closely to the bed. In fact it fits so loosely that during a winter storm the snow would blow inside in such quantities as to completely cover up the scales and permanently stop all action. The hood is fastened to its bed by ordinary hooks and eyes.

The gauge is essentially a storm machine, the first requisite of which must be the complete protection of its internal machinery from water and air currents, either of which will operate against its

normal action and ultimately destroy the value of the record. Even if the base is reasonably water tight, but will admit a current of air, dust will be deposited on the machine, interfering with free action and increasing the resistance of the electrical contacts. In damp weather the scales will sweat, while the steel of the scale bearings will oxidize in almost any kind of weather if exposed to a free circulation of air.

To remedy the evil, I fitted the bed with strips of heavy rubber and placed a piece of thick felt around the door. This answers the purpose fairly well, but the sheet iron hood should be firmly soldered or riveted to a frame of heavy metal cast and ground to accurately fit the bed. Instead of being loosely fastened by hooks and eyes, the hood ought to be firmly bolted to the bed to make the joint as tight as possible. It need never be taken off except in case of accident to the gauge. The door should be made of cast iron ground to fit a frame of the same metal. In short, the hood should be made by a machinist and not so much after the fashion of a tinsmith. One piece of the working mechanism of the scales passes down through the bed and becomes thickly covered with rust and smoke and, from the nature of its exposure, can not be kept clean. It also requires a hole in the bed plate which is large enough to admit a considerable current of air. A small iron box might be fitted over this, a detail which would contribute appreciably to the preservation of the delicacy of the instrument. The top of the copper can, for holding the rainfall, is so flexible that it can easily be bent between the thumb and finger in the ordinary handling of it, making it extremely liable to get out of a true circle and rub against the sides of the hood. This might be remedied by fitting a thin brass ring around the top. The can itself rests loosely on the scale beam and it is never absolutely certain that it is in the center so that it will not touch the cap which fits over it. To remove this uncertainty a small steel point might be soldered on the bottom of the can, in the center, to fit into a hole in the scale beam, always assuring a proper position for the can. This little detail would save a great deal of inconvenience and uncertainty and, occasionally, a record.

The dasher, fitting into a cup of glycerine, is fastened to the scale beam by a rather awkward clutch with no arrangement to keep the dasher in line with the cup. If the clutch is to be used, some means should be found to insure perfect and permanent alignment. The dasher itself is, however, a makeshift to correct an evil which it does not correct, and since attaching the controller I have dispensed with the dasher as useless. The machine was wired from binding posts on the register to a set of binding posts on the gauge bed, thence to a set of binding posts on the frame, thence to the contact points, the whole forming a somewhat high resistance. The under surface of the bed soon rusted badly, covering the insulation of the binding posts with fine rust, which may not affect the insulation in dry weather, but when the rain drops spatter up underneath the wet rust makes a good path for the current, so that the instrument is short circuited and the record ceases.

In order to effectually prevent this I removed the wires from the binding posts, ran them directly, and soldered them to the wires running to the contacts and the gauge magnet, lessening the resistance and the liability to leak.

These changes render the instrument thoroughly storm proof, and reliable action is now the rule and not the exception. However, with these minor details carefully adjusted and reliable electrical action secured, there still remains a grievous fault which renders the record useless in point of time and amount. The gauge is practically like a steam engine without a governor.

In theory the scales are in constant equilibrium, or at least always sensitive to about 11 grains or 0.001 of an inch of water; immediately upon receiving a deposit of that amount the beam settles to the contact point and the register pen instantly makes its mark, leaving a reasonable inference that, as only such a small amount of water has fallen, the storm began a very short time before the mark was recorded. After the first movement the instrument is in readiness to record the next 0.001, and so on. On account of the interference of the wind, in actual practice this theory is far from being realized. With the funnel removed, which is necessary during the snow season, and, therefore, for at least half of the year in this latitude, the scales will be persistently out of balance from 0.01 to 0.03, depending upon the pressure of the wind.

Now, suppose the scales were balanced immediately before a fall of rain which began at 1 a. m. and ended at 1:30 a. m., amount 0.04. At 1:30 a. m. the wind increased and agitated the scales until they were off the balance 0.03 at 1:50 a. m., adding that much to the record, making a total of 0.07 on the sheet. How can it be told positively from the record that it actually ceased raining at 1:30 a. m. and not at 1:50 a. m. as shown on the sheet? How can it be determined whether the extra 0.03 should be taken from the end of the record or from some other portion? Take another case: It begins to snow during the night, the register making its first mark at 1:10 a. m., with the scales known to have been previously blown out of balance 0.02. As snow frequently falls in fine dry flakes at rates which often amount to much less than a 0.01 per hour, how will it be possible to tell from the record the commencement of the storm within several hours? Supposing the storm ceased at the time the machine recorded its first 0.001 and at the end of an hour the wind increased, blowing the scales off 0.03. The evidence on the sheet would tend to prove that the snowstorm occurred as a heavy fall of snow of short duration at about 2:10 a. m. The exact time and rate of fall during a storm are often far more important questions than the total amount of precipitation. On the 27th of last March, rain began to fall at 11:55 a. m., the controller had been placed in the circuit of the gauge as an experiment. A thread holding up the armature was accidentally broken at six minutes after noon and was replaced at 12:37 p. m., during that interval the gauge was free to work over its usual circuit, the funnel, on account of the liability of more snow, had been removed. An examination of this record shows that up to the time when the controller was cut out of the circuit, the precipitation was fairly regular at a rate of about 0.08 per hour; at this moment, the gauge, being suddenly placed at the mercy of the wind which was gusty, made a record of 0.02 at a rate of 0.50 per hour, or more than five times the actual rate. For a space of five minutes no record at all was made, apparently indicating that the storm had entirely ceased for that period. At 12:30 p. m. another record of 0.02 was marked on the sheet followed by a blank of seven minutes; at this point the

controller was again placed in the circuit and the true rate recorded, making a smooth continuous line. From personal observation, the rate of fall appeared to be steady. This proves that at no particular minute can it be determined from the record that rain or snow was falling, which to say the least is a very serious fault.

The so-called controller above mentioned was devised for the purpose of eliminating all effects of the wind and of continually maintaining the scales in equilibrium.

The mechanism of the instrument may be described as follows:

An electromagnet is fastened horizontally to a base. Its armature carries a lever which, when the armature is down, touches an adjustable contact, closing the circuits of the rain gauge, which are otherwise broken at this point. This magnet is placed in direct circuit with the scale contact, the sole duty of the scale contact being now to work the controller magnet and not to produce any action whatever in the gauge or register magnets. The wire from the gauge magnet is disconnected from the scale contact and led through the break on the register to the lever of the controller magnet. The battery wire leads up to the contact point underneath the arm. Above the controller magnet is a system of clockwork, the second hand of which is replaced by a toothed wheel which, of course, makes its revolution once every minute. The axis of this wheel carries a loose pulley. A thread attached below to the armature runs over the pulley carrying a small weight at its loose end. This weight, aided by the usual armature spring, maintains the armature at its highest point. The loose pulley also carries a catch which hangs underneath the minute wheel until the armature begins to descend, when the catch immediately hooks into the wheel, after which the movement of the armature is retarded and can descend only at the speed of the wheel. The time, therefore, which the armature will consume before it finally touches the contact point is governed by the clock.

This arrangement results in preventing the agitation of the scales by the wind from affecting the register, for as such movements are only momentary in character, they only suffice to move the controller magnet a fraction of its distance, while its full movement is necessary to bring about action in the gauge and register magnets. If, however, a permanent weight like rain or snow falls into the receiver, the controller armature settles firmly down upon its contact point, the gauge circuits are completed, and the proper record made. By experiment, I have determined that the scales are never held down by the wind for more than two seconds, and usually for only a small fraction of a second; therefore, I have set the controller magnet so as to allow the register to work every four seconds, or fifteen times a minute, sufficient to give a smooth trace for excessive rates. Thus, the gauge is always ready to record the first 0.001 which falls and gives the true amount at any time up to the last four seconds. The rain trace is, therefore, absolutely true to the fifteenth of a minute, and even that fraction can be eliminated by merely setting the clock ahead four seconds. The gauge scales being always as near equilibrium as its sensitiveness will permit, the knife edges are kept nicely polished, an important item in looking for the best results.

Drosometer.—The gauge scales are sensitive to about 11 grains; an ordinary pair of druggist's prescription scales are sensitive to a sixtieth of a grain. It is, therefore, possible to construct a much more

delicate instrument which will measure 0.0001 or less. With such an instrument, and with the controller included in the circuit, it is only necessary to expose, instead of the copper can, a device for dew, when a trace for that form of precipitation can be as easily recorded as for rain.

INTERCHANGE OF STANDARD CLIMATIC DATA.

ALEX. G. McADAM, New Orleans, La.

As a first premise let us agree that the climatic data of a State or section, as now published in the monthly bulletins, are of sufficient accuracy to warrant use in the scientific discussion of the many problems in agriculture, engineering, and hygiene, daily brought to the meteorologist for solution. If it be conceded that the material already available is of this character, a plea for the increase and diffusion of such matter needs but a presentation of suitable methods to be acceptable.

Doubtless every director realizes the necessity of keeping himself informed of the climatic conditions of other sections as well as his own. Especially must he follow the conditions of districts competing with his own in the markets of the nation. We are all aware how carefully reports of the yield of wheat in Russia, Argentina, and Australia are studied in the United States. The value of our own yield is largely dependent upon conditions existing elsewhere. What is true on the large scale, is true on the small one where different sections are concerned. The conditions in Kansas concern the grain grower in California and *vice versa*.

In the National Crop Bulletin, the information is available in convenient form each week of the growing season. So well is the work accomplished that suggestions for improvement are not easily made. Perhaps, those most interested, the farmers themselves, do not get the full benefit of the information. Possibly it may occur to some one present to suggest a remedy. We admit, though cheerfully, that little more can be desired with regard to the collection and dissemination of standard crop data during the season. The effect of climatic conditions upon crops, while easily chief among the interests of the community, is not the only matter of importance. Manufacturing and the mechanical arts have their place in a publication like the monthly bulletin, and their importance should not be underestimated. In all sections, there are constant calls for rain data from railroad engineers, from electrical engineers, and from mechanical engineers. These calls are now generally answered by letter containing the data desired. Could not such data be preserved permanently by publication and made to serve a larger clientele? Again, there is much scattered information in the possession of each section director which should be published. For example, the fact that magnificent crops can be grown on certain soils in California, with a rainfall which would be considered totally inadequate in many sections, is of interest to every farmer as illustrating the fact that amount of rainfall is not the only matter to be considered in connection with crop yield. The character of the soil, and the mechanical action in the soil, may be of almost equal importance with either the intensity or frequency of rain. Information of this character is just what intending settlers most wish

to know, and to give such information is a proper function of climate and crop work. In the Year Book of the Department for 1897 instances are given where certain crops are grown without irrigation. In southern California "Less than an inch of rain," says Whitney (p. 432), "falls on an average during the five months of the growing season from May to September."

Furthermore, an interchange of data between climate and crop sections, whenever abnormal or unseasonal conditions prevail, would be of value. Imagine a physician about to send a patient to a locality ordinarily well suited in the matter of climatic conditions to bring about recovery. If the patient is sent thither at a time when abnormal conditions prevail, he might experience the very conditions he desired to avoid. Such abnormal periods happen. In California the rainy season—the winter—was almost wholly without the usual rain in 1897-98, and the coldest weather known for years was experienced in some sections. If section directors were in a position to know where abnormal conditions are prevailing, physicians consulting them would certainly appreciate the importance of the information.

Finally, there is room in every bulletin for items of scientific interest. Many reprint short notes, extracts, etc., from the Monthly Weather Review. Could not some plan be devised whereby standard matter could be prepared, and, as in the syndicated articles of the daily press, illustrated, if necessary, and sent to the various sections? To make this more plain, imagine an article on frost, properly illustrated with half-tones showing effective smudging apparatus, frosted fruit, and the topography of frost belts. No individual director would care to stand the expense of the illustrations; but if made in quantity and distributed among twenty, each would cheerfully pay his small proportional share. Such a system would also encourage directors to bring forward papers showing peculiar climatic conditions in their respective sections.

Some one may say that work of the character described is now performed by the Monthly Weather Review. The answer to this is that the circulation of the Monthly Weather Review must of necessity be restricted to three or four thousand copies. The combined circulation of the monthly bulletins approximates twenty-five thousand and is constantly increasing. Furthermore, the readers of the Monthly Weather Review are different from the readers of the bulletins, and what is suited for one class is not for the other. The fields covered are not the same.

We conclude, then, that in the monthly bulletins we have the means for the successful dissemination of valuable climatic data. Can we, by cooperation, improve the good work now being done?

STUDIES OF CLIMATE.

F. J. WALK, Baltimore, Md.

It is very likely that during the course of the next few years the directors of the different climate and crop sections and State weather services will undertake the preparation of monographs or histories as a basis for studies of the climate of their respective sections or States. As far as I know, in one State only, has such a detailed climatic history been compiled and published up to the

present time. I refer to that comprehensive publication, the fourth biennial report of the Oregon weather bureau, prepared by Director B. S. Pague. It is well known that valuable articles of a special nature have been written by the directors of the climate and crop services of Texas, California, and other States; also that the Michigan State Board of Health has utilized meteorological reports in special studies, and that other scientific organizations have made special investigations based on Weather Bureau and State records. While recognizing the importance of these special papers, the fact remains that the Oregon report is probably the only sectional publication yet issued that enters fully into the subject of climate and meteorology in all its phases; in other words, it is the one report in which can be found not only a comprehensive climatic history of a State for the period of years covered by meteorological observations, but also a digested study of the conditions for all these years combined, together, with a summarizing of the climatic features thus disclosed, and of the general laws that must determine, to a greater or less extent, the climatic history of the State in years to come; finally, and probably most important of all, the arrangement of the data contained in the report is such as to provide a ready basis for the preparation of special studies of any nature related to or dependent on meteorological or climatic conditions. It is this point in particular that I desire to bring to the attention of the Convention. It is understood, of course, that no reference is now being made to the weekly and monthly publications of the sections or States; their present methods of issue admirably serve as a concise record of current events, that being the purpose for which they are prepared. But in order, however, to serve wider and more general purposes, I am convinced that the great mass of climatic data now at hand, and constantly accumulating, requires still other forms of combination and arrangement to bring out valuable facts and laws now hidden; that is to say, it is as necessary to decide upon the best methods to be followed in compiling meteorological data as it is to collect the records themselves.

Imbued with this feeling, I have been led to the preparation of a model or outline of a satisfactory and uniform method of meteorological and climatic compilation, and which I will present for your consideration and discussion. This outline is somewhat on the lines that are being followed by the Maryland and Delaware Climate and Crop Service in a publication now in course of preparation. No originality is claimed for the plans set forth. I have simply adapted the methods found in various treatises to my ideas of the needs and demands of the respective sections in the prosecution of their labors.

As a prelude to the plan which follows, I wish to say that the words climate and meteorology have been used and considered throughout in their broadest significance, and not in the specific sense frequently employed by specialists in their several lines of investigation. Let us consider, for the present at least, the more general meanings of these terms, allowing the special relations of climate to soil, health, plant and animal life, etc., to be brought out later if desired, after the firm basis for these special investigations shall have been established by our primary efforts.

By climate, I mean the summing up and averaging of the meteor-

ological conditions of a section for a series of years, together with a determination and study of the average and extreme departures from these average conditions. A necessary condition in this connection is that the period covered by observations shall be sufficiently long to largely eliminate from the averages the excessive influence that might be exerted by the persistence of very abnormal meteorological features during one or more months, seasons, or years. A true climatic history can in this manner be obtained, and studies of the relations of the climate to human, animal, and plant life may then be intelligently carried on.

By meteorology, I mean the observation and study of the transient weather elements and phenomena as produced or controlled by the passage of cyclonic and anticyclonic areas and the attendant secondary disturbances, and an investigation of the characteristics of the more marked types of weather; that is to say, the determination and analysis of the weather elements resulting from the successive formation and movements of these areas.

Having thus expressed the limits within which I have thought it most desirable for our purpose to confine the meaning of the terms climate and meteorology, and with the understanding that it is within these limits that they have been considered in the preparation of the outline given herewith, I will submit the outline itself. I indulge in the hope that its discussion will bring forth valuable suggestions from the members present, many of whom, through long connection with the climate and crop work and an intimate acquaintance with all its needs, are doubtless better qualified than myself to deal with the problems considered in this paper.

OUTLINE FOR A UNIFORM METHOD OF METEOROLOGICAL AND CLIMATIC PUBLICATION FOR EACH SECTION.

INTRODUCTION.

Historical sketch and bibliography, embracing an account of the various meteorological records that have been obtained in the section or State, with the periods covered, and, where possible, the names of the observers. An account of the various stations that have been established. Also, of the publications of all kinds bearing upon the meteorology or climate of the section that may have been issued in or pertain to the section under discussion.

An enumeration and description of the various maps and charts that have been issued.

Establishment of and work done by organized meteorological and scientific bodies in the section, such as the National Weather Bureau, State Weather Services, local societies, etc.

INSTRUMENTS.

Descriptions and illustrations of the ordinary meteorological instruments, especially those in use in the regular Weather Bureau offices and by the voluntary observers.

METEOROLOGY OR WEATHER.

General description of the storm movements over the section: weather types and characteristics; general and local modifying influences; storm frequency and intensity.

CLIMATE.

(a) Geography, topography, and general physical features of the section under discussion; general geology; distribution and kinds of agricultural soils.

(b) Meteorological elements:

Temperature—

Mean daily (as far as possible).

Mean monthly.

Mean seasonal.

Mean yearly.

Average monthly and annual maxima.

Average monthly and annual minima.

Extreme temperatures, monthly and annual.

Amplitude or range; mean daily, monthly seasonal, and extremes.

Variability or average daily change for the single months; also, for the seasons and the whole year.

Temperature anomaly, or the average departure from the normal for the several months (and seasons) for a number of years.

Long period temperature oscillations.

Permanent increase or decrease in temperature.

Temperatures of evaporation, or wet bulb.

Number of days with temperature of freezing or below.

Number of days with temperature above 90°.

Number of days with mean temperature above 42°.

Advance of spring.

Average and extreme dates when ice forms in spring and autumn, and the number of days free from ice.

Frosts, average and extreme dates of first and last light and killing.

Relative frequency of cold waves in winter and hot waves in summer.

Influence of mountains, valleys, large bodies of water, etc., upon temperature.

PRECIPITATION.

Total amounts, monthly, seasonal, and annual.

Excessive amounts, and frequency of excessive rainfall.

Fluctuations in rainfall, monthly, seasonal, and annual.

Long period fluctuations.

Variability or departure from the normal.

Permanent increase or decrease in rainfall.

Average number of days with precipitation, monthly and annual.

If there is a pronounced rainy season, the percentage that the rainfall occurring in that season bears to the total for the year should be given.

The intensity of rainfall, or the ratio between the total amount and the number of days on which it fell.

Frequency or probability of rainfall, by months, seasons, and year.

Greatest number of consecutive days with appreciable rainfall.

Greatest number of consecutive days without appreciable rainfall.

Years of drought.

Destructive storms.

Thunderstorms, average number, and time and region of greatest frequency.

Influence of topography, bodies of water, etc., upon the rainfall.

Hail.

Snow.

Dew.

HUMIDITY.

Relative humidity.

Absolute humidity.

CLOUDINESS.

Number of clear, partly cloudy, and cloudy days, by months and for the year.

Sunshine.

Fog, number of days with.

WINDS.

Average velocity.

Prevailing direction.

Resultant winds.

Frequency, or average number of times the wind blows from each direction.

Months of maximum and minimum velocities of winds.

Highest velocity of winds.

Wind direction most likely to be followed by rain.

Wind direction least likely to be followed by rain.

Local winds, such as mountain and valley winds, land and sea breezes, etc.

Hot winds.

Cold winds.

Foehn winds.

CONCLUSION.

Summary of the principal features and main characteristics of the climate of the section as a whole, and of its several climatic divisions; also a table, or tables, showing a brief comparison of the climatic conditions of the section, or its divisions, with selected places in the United States and other parts of the globe.

Meteorological and climatic problems yet obscure or undetermined, and the best means for their solution, also the adaptation of current methods of work to that end.

VOLUNTARY STATIONS: THEIR OBJECT AND COLLATERAL FUNCTIONS.

A. J. MITCHELL, Jacksonville, Fla.

All human enterprises at their inception are necessarily crude, and, possibly for this reason, it is but natural that they should awaken in the hearts and minds of some, a feeling of incredulity, but with passing time, and the increase of the knowledge begotten of experience, a progressive improvement is the certain result of a liberal and expansive policy. By way of preface, we feel that these remarks are not inapplicable to the Climate and Crop Division of the Weather Bureau, and while we would not detract one iota from the indisputable importance of other divisions, yet our position enables us to

speak with a riper knowledge of the duties in which we are immediately engaged. It is presumed that one of the primary objects in establishing voluntary meteorological stations was to collate data, and in the course of time, deduce reliable normals for future purposes. I believe it is conceded that it will require about forty years to deduce an absolutely correct normal—one that, in the general average, will compensate for all irregularities both of a plus and minus character. The utilization of climatic data progresses with the general mastery of reason and enlightenment over ignorance and indifference. There is scarcely an industry in any State which would not be more successfully operated by studying in advance the indispensable climatic elements, heat and moisture. The importance of success is such that the provident man can ill afford to take any risk. Closely pursuing every failure stalks the specter of poverty in old age, gaunt, repulsive, and hideous, yet, in many cases, a monument to man's lack of circumspection, and his failure to utilize the great facts made evident by the development of science.

That we may more forcibly illustrate our position let us take the industry of orange culture in northern and north-central Florida, and in approaching this subject we wish first to emphasize the fact that there is not a State in the Union possessed of such recuperative forces as Florida; although, almost in the lap of tropical verdure, and bordered on either side by the tepid waters of gulf and ocean, there is a limit to her greatness. We can not grow oranges successfully in the northern part of the State, nor will a residence in any portion thereof change the color of an aspiring black man to the shade of his white brother. However, it rains alike on the just and the unjust, and the tender plants of the Christian brother enjoy no special immunity from the uncharitable touch of winter's frost. In the absence of an established climatic record, emphasizing the possibility of recurring cold waves of sufficient severity to destroy the orange industry over northern portions of the State, many growers with commendable enterprise but faulty judgment failed to hearken to the suggestion of danger to the orange industry north of a certain parallel, and the result to many was not only failure to realize their expectations but a marked increase of liabilities over assets. Although adventurous orange growers may sometimes fail to give necessary attention to vital matters, we feel confident that none would have ignored established climatic statistics and recklessly undertaken to make orange culture a success within a sphere where freezes had been frequent and sufficiently severe to rob the enterprise of its remuneration. Here, then, we are able to appreciate the great importance of the records now being compiled by the various sections of the Weather Bureau. Before the days of agricultural chemistry, soil analyses were deemed an ephemeral myth. The ideal farmer was supposed to be that genus homo who, with more muscle than brain, was an adept at logrolling but knew nothing of the chemistry of the soil, but the advent of a few Secretaries of Agriculture of the type of the one now directing the affairs of the Department is rapidly emancipating agricultural classes from obsolete and profitless methods.

The question suggests itself then, if it be prudent to investigate soil properties before seeding, how much more important is the matter of seasonal and annual normals of temperature and rainfall. Chemistry can supply the deficiencies of the former, while irrigation,

a decidedly more expensive requisite, can alone obviate the latter. Less than a quarter of a century ago we knew nothing of the climatic conditions characterizing a large area of the Transmississippi country. A recognized authority had given the opinion and styled the section alluded to as an arid one, but later we find climatic statisticians demurring to such an opinion, and instead of there being an almost limitless waste of barren plains, it is found that the territory where rainfall is insufficient for agricultural purposes is indeed limited. Years ago the home seeker laid out his itinerary along certain parallels of latitude, and generally with no conception of the climatic conditions essential for the purpose and objects of his future vocation. His actions were governed largely by necessity, for there were no official sources from which reliable data could be had. How different now, for once each day, during the three hundred and sixty-five of each year, the faithful and intelligent voluntary observers are recording the maximum and minimum temperatures and rainfall over an area encompassing 3,602,990 square miles.

The data collected by the Climate and Crop Division is not provincial in its utilization. A recent request upon my office for a second monthly report was supplemented by the statement that the original copy "had gone abroad—was now in England selling land." So we see that these reports frequently partake of the nature of living apostles and distributors of information, "are as bread cast upon the waters to return after many days."

Numbers of controversies arise in the course of ordinary business affairs during a year, an equitable decision of which, without recourse to legal tribunals, is frequently arrived at through the medium of local voluntary stations. I have in view an issue between a railroad corporation and a merchant, the latter bringing suit for damaged goods. The railway company set up the defense that the damage was caused by delayed traffic, due to heavy washouts on the road. Recourse was had to the records of a neighboring voluntary station, and the matter was amicably settled.

In semitropical sections, statistics of rainfall and temperature greatly enhance the investigations of the entomologist in determining the peculiar conditions essential for the propagation of insect life. Data recently furnished from the records of voluntary stations opened up this line of investigation in Florida.

To emphasize the fact that all industries are beginning to utilize the records of the Bureau, a recent request from Germany for rainfall statistics from a certain portion of Florida will fully attest. The applicant was interested in the phosphate industry, and wanted to know the average rainfall during what is locally known as the rainy season. And so we might continue the citation, showing the great work being done by one division of the Bureau; and, in conclusion, it is but just to say that the Weather Bureau is a great storehouse of information, the utilization of whose data is only limited by the knowledge of its existence.

SNOW AND ICE MEASUREMENTS.

HERMANN VOLKER, St. Paul, Minn.

Having occasionally noticed great differences in the depth of snow and thickness of ice reported from stations at no great distance apart,

and understanding from personal experience, through my connection with the Central Office of the Weather Bureau, the importance attached to this subject, I venture a few remarks and suggestions upon the same with a view of improvement in the present method of measurements and consequent greater value of these data.

Remarks.—Snowstorms generally extend over a much larger area and are more evenly distributed than rainstorms; therefore, a reasonable agreement in the depth reported from neighboring stations might be expected. It is also true that the amount of snowfall is not influenced by the conditions of city and country; but it is a well-known fact that in cities snow drifts much more and more irregularly than in the country, and that evaporation goes on more rapidly even at temperatures far below freezing. In northern latitudes, the ground in the country is not often entirely without snow cover, after the season for it has set in, but in cities it happens repeatedly if the snowfall is light and at long intervals. Such measurements of the depth of snow on the ground as best represent the true depth with which the country is covered in general are most valuable to the interests for which these data are recorded. Telegraphic reports of snow whose depth is 0.5 inch or less are published in the snow and ice chart as "trace." Five-tenths inch is considered a valuable snow cover, especially from an agricultural standpoint; but, except when snow is actually falling, the ground is usually bare in many places when the amount is less than 0.3 inch.

Where possible ice is harvested from lakes. Ice companies clear away the snow as soon as the thickness of ice will permit, since the presence of snow greatly retards the growth of the ice. They make many measurements from day to day until the ice harvest commences, after which, of course, the cuts will show the thickness. The thickness of the ice from which the crop is harvested is considered to be the thickness for the locality, and therefore the proper amount to be recorded, reported, and published.

Suggestions.—Snow measurements to be exact should be made in the country; but as that is generally impracticable at regular Weather Bureau stations, they should be made as far out in the suburbs as possible, in places least exposed to drifting; a sufficient number of measurements should be made, and at reasonable distances apart, to assure the observer that a fair average of the surrounding country has been obtained. The amount that fell at the station since the last measurement should, of course, be added, if snow is falling at the current p. m. observations. An extra word should be added to the snow code, representing from 0.3 to 0.7, inclusive, as half an inch; trace should be represented by 0.3 or less.

Ice measurements should, when possible, be obtained from local ice companies, and from the spot where they expect to harvest. The Central Office should be informed, before the season opens, as to how and where snow and ice measurements are obtained, so that a statement thereof can be made when required or desired.

I believe that any improvements, such as mentioned above, will give satisfaction to the Bureau and to all interests concerned, and that every observer will, after the first quarter of the season is over, be pleased with the result obtained, in the better agreement of the amounts reported from neighboring stations, and in this way be compensated for a little extra effort in that direction.

J. C. PIERCE, North Platte, Nebr.

I will mention only a few of the innumerable benefits of the Weather Bureau. The Bureau is of great importance to every part of Nebraska, where the climate is so vital a consideration in settling the country. I am satisfied that were it not for the many counties which are now prospering under the advantage of fertile soil would still be prairie. The first meeting of the Nebraska State Irrigation Association was held in North Platte, Nebraska, and being invited to speak before the association on the rainfall of western Nebraska, I stated that the rainfall was not sufficient for successful farming, and that irrigation was a necessity. This has been fully verified, for the successful farmer of to-day is the one who irrigates. Thousands of acres of land are now irrigated which irrigation was not practiced a few years ago.

To show the importance of the precipitation data to the farmer, I will say that it is only a few days ago that the mayor of North Platte, who is an extensive landowner, requested to be furnished with the rainfall from 1875 to 1897, and had me certify to its accuracy before a notary public. The dissemination of data by the Weather Bureau has made this country a resort for the benefit of humanity. By personal observation I can say that the weather passes at this time of the year but that a sufferer from the effects of the (sometimes nearly dead) stops at North Platte in hope of being benefited by the dry and invigorating air, and I am happy to see that the climate improves them.

DEVELOPMENT OF THE DAILY WEATHER.

By EDGAR B. CALVERT.

One of the best known features of the work of the Weather Bureau is the daily weather map issued to the public. The development of this chart from the primitive cartographic present well-known forms is quite interesting.

Some years prior to the establishment by act of Congress of the first weather service (Signal Service) February 9, 1870, weather maps were prepared by a few scientific men from private means. Prominent among these persons was the late Dr. Carl Land Abbe, who has been with the Weather Service since its organization, and is now senior professor on the scientific staff of the Weather Bureau. But it is the purpose of this paper to briefly trace the development of the official daily weather map.

The first official weather map of the Weather Bureau was a manuscript by Prof. I. A. Lapham, Chicago, Illinois, in 1871, but it was not until January 14, 1871, that the first official weather map for distribution was begun at Washington. The first map for distribution was by means of a process of rubbing between blank tissue maps. From this process the maps were arranged together in this way and the impressions were made by means of a slow and laborious process. These maps were stamped separately. These maps were

and temperature, state of weather, wind direction and velocity, and precipitation, but no isobaric lines.

The manifold method was dispensed with on April 30, 1871, and in its stead a brass bed-plate map was used, on which all the cities from which reports were received were indicated in their proper positions by small square holes mortised in the bed-plate. Steel symbols, representing the eight wind directions and the different weather conditions, were placed in these holes so as to form a printing surface. Close to each of these holes slots were cut into which were set the figures showing in regular order temperature, barometer, and wind velocity. The plate so prepared was placed in an ordinary proof press and impressions printed therefrom. Weather forecasts, then called "probabilities," and a synopsis of the general weather conditions that prevailed within the area represented by the charts were first printed on the maps October 1, 1871. These, with some changes, have continued to be an interesting and valuable feature of the daily maps. The barometer and temperature lines were still omitted from the charts, but on October 30, 1871, when the lithographic process was adopted, the isobars were added. The bed-plate was not entirely dispensed with, as impressions were still taken from that on prepared paper, the highs and lows and lines added by hand, and the whole transferred to lithographic stones. On April 15, 1872, the isotherms first appeared on the chart. With few modifications from time to time in the kind of symbols used, number of reports indicated, shaded precipitation areas, etc., the same process has continued in use at the Central Office up to the present time.

After the adoption of the bed-plate and lithographic process by the Washington office the steel dies used in making the carbon copies were sent to a few of the stations of the Bureau, but their use was very limited.

In 1876, during the Centennial Exposition, an attempt was made to send the lines of the daily weather map by means of autographic telegraphy. The chart was telegraphed in this way each morning from the office of the Chief Signal Officer at Washington to the Signal Service Exhibit in the Government Building at Philadelphia, and there reproduced and distributed. However, this scheme was not afterwards continued because it was impossible to obtain an exact reproduction, especially at great distances.

In 1879 a contract was made with the New York Graphic for printing a weather map in its daily issue, and the first chart was published on May 9, 1879. In appearance it was very much like the chalk-plate maps now seen in the newspapers of some of our large cities, but the zincograph method that was used in preparing the plate is little known or used at the present time. This chart was first drawn on paper with copying ink and then transferred to a metallic base. The lines and figures were then carved or etched in this metallic base, which was used as a mold for casting the plate from which the printing was finally done. The Graphic continued to print this chart for some years, for which service the Government paid \$10 per day. In addition to this about \$15 per day were expended for the material used in preparing the chart and for telegraphing reports and instructions for drawing the barometer and temperature lines. The work of telegraphing the lines was accomplished by means of a lettered and numbered diagram covering the daily map at Washington,

a key to which was in the hands of the observer at New York. At that time no one outside of the forecast official in the Washington office was permitted to draw barometer and temperature lines and to locate highs and lows.

Prior to 1886 charts could not be issued from stations in large quantities, for the reason that there was no process whereby they could be prepared speedily and without great expense. It was not practicable to place a lithographic plant at the different stations of the service. In 1886 the cyclostyle method was tried with success, and in August of that year it was put into operation at the New York station. Within the next few years it was introduced generally throughout the service. This process is quite simple, and, to some extent, is in use at the present time. A specially prepared stencil sheet of waxed or paraffined paper, not unlike parchment in appearance, is tightly stretched on a hinged frame that is fitted over a zinc bed-plate. The map to be copied is placed on the bed-plate under the stencil sheet, and the stations marked in the latter by means of a perforating punch. The lines and figures representing the temperature, barometer, wind velocity, etc., and the symbols indicating wind direction and state of weather, are cut into the stencil by means of a peculiar pen that consists of a small corrugated or milled wheel made to revolve freely. The corrugations on this wheel cut into the stencil paper, leaving a series of small holes through which the ink can be forced by means of a regular printer's roller. In printing off each impression it is required that a blank map be placed on the zinc bed-plate, the frame lowered, and an inked roller passed over the stencil. By this process remarkably clear and artistic maps were often made, depending on the skill of the person preparing the stencil. However, there are objections to this method of printing the weather map, as an accident at the beginning of the issue may ruin the stencil and render it impossible to make further prints therefrom.

In 1890 the milliograph was substituted for the cyclostyle, and it is now used by the Weather Bureau in nearly all work where a stencil is required. This process differs from the cyclostyle only in the fact that the stencil sheet is placed over a pad thoroughly saturated with ink. Impressions are made by a dry roller passing over the blank map placed above the stencil. The advantage of this method over the other is that the tendency to break the stencil is reduced to a minimum, and a certain number of legible maps always can be obtained. However, after a few hundred maps have been run off by the milliograph the copies become smeared and illegible.

On August 20, 1892, there was published in the Atlanta Constitution a reproduction of the weather map for that day, and each day thereafter the current weather map appeared in the columns of that paper. This map was prepared by the chalk-plate process, now well known and much used in newspaper work. A preparation of chalk is made to adhere to a smooth steel plate, forming what is known as the chalk plate. With a sharp steel stylus an outline of the map of the United States and the weather data is drawn through the chalk down to the hard, steel surface. The plate is then placed in a casting box, into which molten type metal is poured. The hot metal fills in all the places cut by the stylus, the result being a perfect cast which can be locked up in a newspaper form. When the work is well done the impressions made from such a cast are sharp and distinct.

Since 1892 many of the large newspapers of the country have made a feature of publishing in their columns the daily weather map.

In 1893 the first map stencil was prepared on a typewriter at the Minneapolis station. Since that time several stations have made the stencils in this way, a typewriter with special characters being required. A few months ago the Chief of Bureau directed that experiments be made with a view to determining whether the small charts, such as are used in the chalk-plate process, could be used for the typewriter form. The results have been satisfactory, and directions have been issued to gradually substitute these small charts to be prepared on the typewriter for the large chart issued by the hand-stencil process. This will result in not only a more legible map, but in economy of expense and time, as but one small stencil will be required.

In the early part of 1896 the present chalk-plate and printing process was adopted. It does not differ materially from the method used in preparing the newspaper map. The charts printed in this way are eminently satisfactory, and artistic work is done at many stations. An unlimited number of perfectly legible copies can be printed from the plates. On account of the great first cost of the stereotyping apparatus and complete printing outfit, press, type, etc., required in issuing maps in this way, it is not practicable to establish printing stations at any except the large offices. Printed maps are now being issued from 28 stations. These printed charts are of much smaller form than the old station issue, being about 16 inches long and 11 inches wide.

In a comparatively short time all the maps issued from stations will be of a uniform size, either in the printed or typewritten form. The following table shows the yearly issue of the weather charts :

Fiscal year.	Number of stations.	Number of maps issued.		Fiscal year.	Number of stations.	Number of maps issued.	
		Annual total.	Daily average.			Annual total.	Daily average.
1897	31	175,397	490	1893	74	2,165,649	5,935
1898	40	353,230	1,060	1894	73	3,136,892	8,598
1899	29	859,027	2,355	1895	76	3,609,215	9,890
1900	41	1,068,862	2,925	1896	77	3,802,600	10,430
1901	52	1,198,899	3,280	1897	80	4,625,250	12,600
1902	70	1,817,120	4,980	1898	84	5,239,900	14,350

. It is seen that the issue of the daily weather maps has greatly increased since the year 1886, when the first attempt was made to supply the general public in this way with information in regard to weather conditions.

Since 1870 there have been several changes in the hour of taking the observations telegraphed for entry on the forecaster's chart and the daily weather maps, a corresponding change in the hour of issuing the published maps being necessary :

Washington time.—November 1, 1870, to August 25, 1872, 7:35 a. m., 4:35 p. m., and 11:35 p. m.

August 25, 1872, to October 31, 1879, 7:35 a. m., 4:35 p. m., and 11 p. m.

November 1, 1879, to December 31, 1884, 7 a. m., 3 p. m., and 11 p. m.

Changed to seventy-fifth meridian time, January 1, 1885 (difference, 8 minutes).

Seventy-fifth meridian time.—January 1, 1885, to December 31, 1886, 7 a. m., 3 p. m., and 11 p. m.

January 1, 1887, to June 30, 1888, 7 a. m., 3 p. m., and 10 p. m.

July 1, 1888, to date, 8 a. m. and 8 p. m.

From the date of issue of the first tissue chart by manifold process in January, 1871, to July 1, 1888, the Washington map was published thrice daily, although the charts prepared from the morning observations were the only ones generally distributed to the public. From July 1, 1888 to September 30, 1895, the maps were issued twice daily. On the latter date the p. m. chart was discontinued, and since that time there has been but one daily issue.

It is not possible in this paper to state in detail the history of the station charts. For a number of years they were published twice daily at the larger stations of the service, but it was found that in most of the cases one issue a day would be sufficient. At but few stations are maps now prepared for general distribution both from the morning and evening observations. These changes do not refer to the manuscript pencil charts prepared at forecasting centers for use by the forecaster in making twice-daily predictions of expected weather conditions, and, whenever necessary, warning of marine storms, frosts, cold waves, heavy snows, etc. The original plan of entering with pencil the data for each observation, whether tridaily or bidaily, on blank tissue charts as fast as received over the telegraph wires has never been changed. The maps so prepared are used almost exclusively for forecasting purposes and study.

From the beginning of our national meteorological work, it became apparent that the daily weather maps would not be complete without daily reports from the regions north and south of the United States. It was not possible at first to obtain telegraphic observations from many stations in the United States west of the Mississippi River, due to the absence of telegraphic lines. The early bulletins contained data from Omaha, Nebr., and Cheyenne, Wyo., reports from Corinne, Utah, and San Francisco being added about January 1, 1871. As fast as it was possible to do so, stations were located in every section of the western country, keeping abreast of the march of progress and civilization as the electric telegraph brought that vast, undeveloped country into close touch with the Eastern States. Efforts to obtain daily observations from the regions beyond our northern boundary met with early success. On November 13, 1871, an arrangement was made with the Canadian Government for an exchange of reports, whereby the meteorological office at Toronto would telegraph to us their observations and we, in turn, give them such reports as they desired. This cooperation has continued up to the present time. It has resulted in vast benefit to both countries, especially since stations were located in the British Northwest Territory, where most of our cold waves make their appearance. By means of observations taken at stations in the United States, the Canadian Meteorological Office is enabled to forecast the numerous storms that move down the St. Lawrence Valley out into the ocean.

The work of obtaining daily reports from the countries and islands to the south of us proved a more difficult task. Professor Abbe makes reference to this subject in his paper which appears in a

report of the Meteorological Congress held in Chicago in 1893. He says:

The need of more reports from the West Indies, especially during the hurricane season, was very deeply felt in 1871, * * * but this invasion of foreign countries, and especially the transmission of cipher dispatches, presented many objections which could be overcome by international courtesy. Three stations were opened in 1872 and began to report in August or September of 1873. Three more were opened in 1874.

General Myer and General Hazen, during their administrations of the Signal Service, made repeated attempts to inaugurate a system of reports from the West Indies, but with discouraging results. In their annual reports these officers referred to these failures and attributed them to imperfect arrangements for cabling, incompetent foreign observers, and lack of sufficient appropriations.

During General Greely's administration of the weather service as Chief Signal Officer arrangements were made for receiving daily cablegrams from a cordon of stations in the West Indies, the observations being made by native observers from instruments furnished by the United States Government. On account of its great expense this plan did not continue long in operation. It gave way for a system whereby special observations were taken and cabled by native observers whenever conditions indicated the presence or approach of a tropical hurricane. During Prof. M. W. Harrington's administration as Chief of the Weather Bureau provision was made for receiving special observations from Yucatan, in Central America. The value of the observations from the West Indies and Yucatan was demonstrated again and again in forecasting destructive hurricanes approaching the Gulf and south Atlantic coasts of the United States. It was not until the summer of 1898 that the complete weather map, the dream of the men who engaged in the early struggles for the organization of the National Weather Service became a reality. During the recent war with Spain, when the scenes of naval operations were for the most part laid in the waters of the Caribbean Sea and Gulf of Mexico, the necessity for daily observations from these regions became apparent. Our blockading squadron could not then enter Cuban harbors. As the hurricane season approached the possibility of our fleet being scattered and seriously damaged by one of these severe storms became a matter of serious concern to the President and the naval authorities in Washington. At the urgent solicitation of Honorable James Wilson, Secretary of Agriculture, Congress authorized and made appropriation for a meteorological service in the West Indies, to be established by the Weather Bureau under the direction of the President. Trained officials from the regular service of the Weather Bureau were sent to man the West Indian stations, taking with them complete equipments of standard instruments. Kingston, Jamaica, was selected as the temporary headquarters of the new service, and arrangements were perfected for cabling the reports twice daily to that place, and to the Central Office at Washington. On August 11, 1898, thirty-five days after Congress authorized the service, West Indian reports were entered on the daily weather map at Washington. The value of this work to the commerce and shipping of all nations trading with those islands of the sea was soon demonstrated. On September 24, 1898, the Weather Bureau official at Kingston gave warning, to all ports that could be reached, of a

hurricane that proved to be one of the most terrible that has visited that section of the world since 1861.

It was also in the summer of 1898 that successful negotiations were made with the Mexican Telegraph Company for an exchange of meteorological reports. Observations from four Mexican stations are now received during the hurricane season and entered on the Washington map. It is intended to place standard American instruments at these places, so as to make the reports therefrom thoroughly comparable with our own.

The mechanical appliances for producing weather charts are sufficiently perfect to meet all present requirements, and the area covered by the daily observations is great enough for practical forecast purposes. It is now possible to produce the charts at stations in unlimited quantities and in legible form.

ESTABLISHMENT AND INSPECTION OF VOLUNTARY, RIVER, AND COTTON-BELT STATIONS.

J. B. MARRURY, Atlanta, Ga.

Since the transfer of the Weather Service of the United States to the Department of Agriculture, in 1891, the relationship between this service and the agricultural interests of the country has grown closer and closer each year. The territory covered by the observations now embraces the major portion of every State and Territory in the United States. The development of the National Climate and Crop Service has been far more rapid than its most sanguine supporters in the beginning dared hope, until its work now ranks second only to that of making the daily forecasts, the widespread distribution of which is made possible through the various sections of the National Climate and Crop Service.

This branch of the Weather Service, when first organized, had the active cooperation of only a few of the States, but the importance of the undertaking soon manifested itself so plainly that the Weather Bureau completed the work, and now the service embraces every State and Territory. There are at present more than three thousand voluntary observation stations, whose records are becoming more and more valuable in the formation of the climatic history of our country as the period covered by the observations is lengthened. These records are especially valuable to the farmer and others interested in agricultural pursuits, since the stations for the most part are located in small rural towns and villages, where the instruments can be exposed near the ground, free from the many artificial influences found in our more thickly populated cities. The conditions of the atmosphere thus obtained are closely allied with those directly affecting plant life.

The reports from our voluntary observers form a most important aid to the student of climatology, since they embrace many sections of the country which are not and can not be represented by the regular paid Weather Bureau observers. To be of the fullest value it is imperative that the instruments and records be correct, the observations carefully and accurately taken, and the best possible exposure be given the various instruments. I am convinced, by personal experience, that nothing can contribute more toward securing reliable

and accurate observations than an occasional inspection of voluntary stations by the directors. It is certainly very important that the men or women who are willing to freely give so much of their time and labor to the work be properly instructed in the very beginning as to the best manner of performing the duties required and, from time to time, encouraged by a personal visit from the director who could thus help them over many temporary obstacles much easier than by letter. These visits would, I am sure, not only increase the accuracy of the reports, but would awaken a new interest in the work. We all need a little encouragement now and then, and when given in person it goes a great deal further than when given on paper, which is cold and unsympathetic at best.

I think each new station should be started under the personal supervision of the director whenever possible. A few moments devoted personally to instructing one of no experience in handling the instruments will give far better results to both the observer and the Bureau than many letters.

To one who has had no experience with a self-registering thermometer or a rain gauge, it is a difficult matter to grasp their proper management from the pamphlet of instructions or from letters; especially is this true with observers who are men of limited education, who, when they see the instruments for the first time, think it impossible for them to master the situation and it not infrequently happens that it is only after the utmost persuasion that they are willing to accept the position. Many of this very type often prove to be most valuable observers.

This country has by far the best equipped weather service in the world as well as the best and most extensive field for its operations, and it should certainly be made of the greatest practical as well as scientific value.

The expense connected with the inspection of the voluntary stations would be small when compared with the good results. With but few exceptions the railroads throughout the country would willingly furnish free transportation, so that the only expense would be for meals and lodgings which, in many instances, would be gladly furnished by the party visited. It seems to me that the results would far more than counterbalance the outlay, and I am sure a marked improvement would be seen in a comparatively short time. I have talked with several railroad officials on this subject, and each one has expressed his willingness to aid in every way possible.

In evidence of the incorrect exposure of the instruments that often exists I will cite one or two of several instances that have come to my notice during the past few years. Upon visiting one station in Georgia I found the thermometers attached to the west side of a building, and the only obstruction to the direct rays of the afternoon's sun was a black umbrella. It took but a few moments to remedy this evil. A second observer had his thermometers on the north side of his house as required, but close in the corner where the chimney to his cookroom joined. The instruments thus received considerable artificial heat from the interior. Another had his thermometers hung in his hall and would open a door at either end a few minutes before taking an observation. I have little doubt that many similar experiences have been met by some of the officials present to-day.

Two other classes of observers needing the personal attention of

the officials in charge of their sections are the river and the cotton-region observers. With many of these there is often as much as or more trouble than with the voluntary observers, since they, in many instances, do the work simply for the money consideration, while with the voluntary observer, the interest he has in the subject prompts him to use the utmost care. The trouble with some of these latter classes is due as much, or more, to carelessness as to ignorance, and they need a little instruction now and then.

It would probably not be necessary to visit these stations as often as once a year except in rare cases. The importance of correct river observations will be fully recognized when we consider the value of the data in determining the proper location of water-power plants, as well as the effect of floods or extreme low water upon commercial and agricultural interests.

Water power has always been recognized as the best and cheapest means of running stationary machinery, and with the more recent inventions and improvements in electrical appliances making possible the long-distance transmission of power a new era in water-power development has been brought about. It is rapidly replacing the earlier methods of generating electricity for lighting our cities and furnishing power to our factories. Under the old methods factories had to be built along the courses of the streams, but there is no longer any such need. The more modern plan of placing the generating plant on the streams, and by means of wires transmitting the power to any point where it is needed is infinitely better. Capitalists are now erecting these plants on the banks of many of our rivers and water courses to furnish light and power to adjacent cities, but before they are willing to expend their money they naturally desire to know from official statistics all about the flow of water in the stream, whether it is likely to give sufficient power the year round, or whether there is danger of its drying up at certain seasons. In short they want to be able to ascertain the discharge of the stream every day in the year. These data can only be furnished from the various river records. It is therefore plain that these records should be carefully and accurately kept, for in computing the discharge at different stages a discrepancy of a few inches in the gauge readings will cause serious errors.

Similar reasons exist for the inspection of cotton, corn and wheat region stations, but it will be impossible and unnecessary to give them in this paper.

* STORM SIGNALS ON THE GREAT LAKES.

J. H. Cox, Chicago, Ill.

The agitation for a national weather service originated with Espy, Redfield, Loomis, and Henry on the Atlantic coast, but was soon taken up in the Lake region. Owing to the many disasters which overtook vessels during stormy weather on the Great Lakes, especially on Lake Michigan, Dr. I. A. Lapham, of Milwaukee, advocated a storm warning service as early as 1844. In a letter written in 1858 to the president of the Detroit and Milwaukee Railroad Company, which had just begun to operate a winter service of steamers between Milwaukee and Grand Haven, he said :

One of the greatest difficulties and dangers against which you will have to contend arises from the sudden stormwinds which so often and so unexpectedly put the sailor upon his hardest service to keep his vessel from shipwreck. During most of the time the winds on the lakes are light and not unfavorable to navigation, but after a number of days of fair weather a sudden and often unexpected change occurs, the wind hauls around toward the westward and blows for several hours a strong gale. On the ocean such gales are not so much dreaded, for there is sea room enough to enable the vessel to ride out the storm, but upon the lakes it is often only by the most extraordinary efforts that the vessel can be kept "off-shore."

It was mainly through the agitation of Dr. Lapham and Gen. H. E. Paine, both of Milwaukee, that Congress passed a resolution in February, 1870, creating a weather service. Immediately after its establishment Dr. Lapham was appointed assistant to the Chief Signal Officer and was assigned to the Chicago station with instructions to issue storm warnings for the Lake region; in fact Chicago was then, as now, a forecasting center for the lakes.

The first dispatch sent out from Chicago was dated at noon on November 8, 1870, and was directed to be bulletined at once by the observers on the lakes. It was as follows:

High winds all day yesterday at Cheyenne and Omaha; a very high wind reported this morning at Omaha; barometers falling, with high winds at Chicago and Milwaukee to-day; barometer falling and thermometer rising at Chicago, Detroit, Toledo, Cleveland, Buffalo, and Rochester; high winds probable along the lakes.

Such was the beginning of the storm warning service. The warnings were first confined to advisory messages, then to storm signals, afterwards to storm and cautionary signals, later to storm and information signals, until at present forecasts are sent to all lake stations daily, in addition to messages ordering the hoisting of storm signals, the latter being issued only when severe storms are expected.

All storm signal orders are verified, each station having its own distinct verifying velocity. These verifying velocities have been changed from time to time, depending upon the elevation and exposure of the anemometers. A proper and satisfactory verification of storm signals is as difficult to secure as a satisfactory verification of ordinary weather forecasts. For purposes of comparison, I have taken from the monthly reports of storm signals of the nine stations on the upper Lakes the number of verifying velocities with direction which have occurred during the past five years. The minimum verifying velocity at the station has been taken as the basis, ranging from 42 miles at Chicago down to 28 miles per hour at Marquette and Green Bay. These winds occur more frequently in March than in any other month, leading with 14 per cent, February and April following with 12 per cent. (See Table I.) The stormwinds are sporadic particularly during the warmer weather. In but two storms during the 5-year period have verifying velocities occurred at all nine stations on the upper Lakes, and in but 15 storms have such velocities been reported at eight stations. If the force of storms was felt, as a rule, equally on all the lakes, and the existing verifying velocities were relatively exact, all stations would have approximately the same number of such velocities during a period of years. Yet there is a great difference between the number of stormwinds at the various stations, ranging in five years from 317 at Marquette to 85 at Grand

Haven. (See Table II.) While there may be reason for some difference, it is impossible to believe that dangerous storms are four times as frequent at Marquette as at Grand Haven. Topographical features play a most important part in the force of the wind and its direction, often permitting winds from certain directions only. (See Table III.) At Duluth, a storm velocity from the east, southeast, south, or west has not occurred in five years, while the percentage of northeast to northwest winds, which may be considered on-shore, was 83 per cent of the total. At Marquette, these winds are mainly from a southerly direction, 72 per cent being off-shore. At Sault Ste. Marie, the percentage of northwest winds alone is 77 per cent; at Alpena, the percentage of westerly or off-shore winds is 70 per cent; at Port Huron, 81 per cent; at Milwaukee, 71 per cent; at Green Bay, 61 per cent; at Chicago, 66 per cent is off-shore; but Grand Haven, with its unusually small number of stormwinds, has 71 per cent of them from the dangerous or on-shore direction. Of the nine upper Lake stations, six have 70 per cent of the stormwinds off-shore, and the remaining three have 74 per cent of these winds on-shore.

The great percentage of northwest winds at Sault Ste. Marie is remarkable, but it is hardly fair to consider these winds entirely on-shore, as the town is situated on St. Marys River below Whitefish Bay; moreover, the velocity of northwest winds is always much greater at the Sault than out on Lake Superior. In fact, the wind velocity at that point from the northwest is so great that it is always out of all proportion to the barometric gradient. There is no doubt that there is a strong suction down the valley, which runs from northwest to southeast, and the wind continues high from Whitefish Point down, long after the wind on the lake has become only fresh or light.

At Green Bay practically no high winds from northeast to southwest occur, which is due to the high cliffs on Limestone Ledge, situated about two miles to the east of the station. The minimum velocity required to verify signals at Chicago is 42 miles per hour, but when the wind exceeds 34 miles from the north or northeast for a few hours, but very few vessels will leave port. A velocity of 40 miles from the northeast after four or five hours will absolutely prohibit navigation at the southern end of Lake Michigan. Yet a southerly wind of 45 or 50 miles per hour just suits vesselmen going northward. Captains say it is extremely difficult to take vessels out of Duluth Harbor after the wind has been blowing 30 miles an hour from the northeast for a few hours, but that a 45-mile wind from the southwest is very favorable.

On September 4, 1897, the writer was proceeding westward from Sault Ste. Marie to Marquette, keeping about 3 or 4 miles from shore. A strong southwest wind was blowing during the entire day. The records at Marquette show that the wind averaged from 30 to 32 miles an hour, which is a storm verifying velocity. Yet on account of its being off shore, the wind had no appreciable effect upon the boat. The captain of the vessel stated that an on-shore wind with much less velocity would compel him to seek shelter in the nearest harbor.

In answer to an inquiry from me, the observer at Marquette recently said:

Southerly winds do cause our register to record higher velocities than north

or northwest winds, notwithstanding the high ridge of hills or mountains extending east and west, and just 1 mile south of the station. I have given this subject a good deal of thought, and am of the opinion that the deficiency of wind movement from the north and northwest is because the anemometer is only 10 feet above the crest of a hill, which extends east and west and is located about 600 feet north of the station. My reason for this presumption is that captains coming into port frequently report heavy on-shore winds outside the harbor, while within the city the wind is hardly 60 per cent as strong. Presque Isle is 3 miles north of the station along the Lakeshore. When the estimated velocity is 30 to 35 miles northerly at that point, our register records about 22 to 28 miles. I will request an extra anemometer at an early date, and have it installed at Presque Isle for comparison with our record. I believe that the verifying velocity of off-shore winds should be increased, and that of on-shore winds reduced. To make a plain and unbiased statement, southerly winds are no impediment to navigation and of no consequence to any one, even though attaining a velocity of 60 miles an hour from the south, as occurred September 21, 1893. A northerly wind of 17 miles velocity at the station in three hours almost prohibits navigation, except by the best vessels, and a 22-mile wind for four hours will have filled the harbor with vessels seeking shelter, including such vessels as the *Northwest* and *Northland*.

In a recent communication the observer at Port Huron said:

A 25-mile wind from a northerly direction, especially from the north to northeast, causes a very heavy sea at the southern end of Lake Huron, as the wind has a long sweep down the Lake; and if it continues blowing any length of time the largest vessels lay over and wait for the sea to run down. Steamers with other vessels in tow are unable to make any headway, and their officers consider it is simply a loss of fuel to try. Navigators do not mind a 30 or 40 mile southerly wind when bound up the Lake, as it helps them along in their course.

On February 20, 1898, the steamship *City of Traverse* left St. Joseph, Mich., bound for Milwaukee, Wis. It encountered nothing stronger than fresh winds, but nevertheless, the vessel within an hour after leaving port, ran into a tremendous sea from the north, due to a gale which had blown the day before, and also to the high winds which were still continuing farther down the lake. The captain was obliged to abandon his plan of reaching Milwaukee and ran southwestward to Chicago for shelter, having nearly all the movables on board, such as dishes, broken to pieces. The inability of the vessel to proceed on its course was due entirely to the tremendous sea, as it actually passed through no strong wind whatever.

The question of sea room, referred to by Dr. Lapham in his letter forty years ago, receives most important consideration at the hands of sailors on the lakes, when on the windward shore. Whenever possible, captains take the leeward shore, moving along under its protection, often when it would be impossible for them to make any headway on the opposite side of the lake. It is of almost daily occurrence for the Chicago weather bureau office to advise vesselmen as to what course to follow on the run down the lake, in order to avoid on-shore winds.

It is surprising what little effect off-shore winds have on vessels. In order to cause a high sea, the wind must have a sweep of many miles. It is the heavy sea that causes so much trouble to shipmasters, as a gale, unless accompanied by heavy seas, is not to be feared. The effect of a gale is more easily apparent upon the fresh water of the lakes than on the ocean, where the water is heavier. However, during summer squalls of short duration well built vessels are seldom troubled, as the high wind must continue for some time in order to make a sea.

It is not strange that by far the greatest percentage of storm winds is from a southerly direction, as the most common track of storms over the upper Lakes is directly over Superior, causing a general southerly current in front of the disturbance. The barometric gradient, as a rule, is much greater in front of such storms than in the rear, so that when the wind shifts to west and northwest it is generally with less velocity. Moreover, strong southerly winds almost always occur with rapidly rising temperature, the thermal gradient playing a most important part in the production of such winds. While the colder northerly winds may move with less speed, yet the air is denser and the momentum or striking force is probably therefore greater. In this connection it may also be said that the destructive force of heavy seas upon vessels increases as the temperature of the water decreases.

It is my opinion that the verifying velocities should be revised, increasing in nearly every case the verifying velocity of off-shore winds and decreasing that of on-shore winds. The need for this revision is particularly evident at such places as Marquette, Port Huron, and Chicago. Southerly verifying velocities often occur at Marquette in connection with disturbances moving over Lake Superior, which are not in the least dangerous. A storm verifying velocity should be a wind which is actually dangerous to shipping.

By supplementing the record of Marquette with a wind record at Presque Isle, and that of Sault Ste. Marie with a record at Whitefish Point, data would be furnished that would be most interesting and valuable. As the wind record at the Sault is not a fair indication of the wind's force on Lake Superior, I think that its verifying velocity from the northwest might with good reason be increased.

Again, it might even be advisable not to assign any verification to storm signals. Frost warnings are not verified, though the writer believes that it is easier to secure a proper and fair verification of frost warnings than of storm signals.

TABLE I.—Percentage of verifying velocities, by months, for each station on the upper lakes, 1893 to 1897, five years.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Duluth, Minn.	5	14	10	13	8	7	6	6	9	6	7	9
Marquette, Mich.	6	11	11	9	7	5	4	5	13	13	9	7
Sault Ste. Marie, Mich.	8	14	15	7	8	4	3	3	12	9	11	6
Average for Lake Superior.	6	13	12	10	8	5	4	5	11	9	9	7
Green Bay, Wis.	8	8	13	12	19	6	2	2	6	11	7	5
Milwaukee, Wis.	12	18	17	15	9	1	1	3	6	7	5	5
Grand Haven, Mich.	13	15	15	16	6	1	1	5	5	5	12	6
Chicago, Ill.	9	8	15	13	10	7	3	3	6	6	11	9
Average for Lake Michigan.	11	12	15	14	11	4	2	3	6	7	9	8
Alpena, Mich.	13	15	15	11	11	2	2	2	6	4	9	10
Port Huron, Mich.	7	11	18	10	9	3	2	4	8	9	12	5
Average for Lake Huron.	10	13	17	10	10	2	2	3	7	7	11	8
Average for the upper lakes.	9	12	14	12	10	4	3	4	8	8	9	7

TABLE II.—Total number of verifying velocities for each month for each station on the upper lakes, 1893 to 1897, five years.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
Duluth, Minn.....	5	16	11	15	9	8	7	6	10	7	8	10	112
Marquette, Mich.....	19	35	36	27	23	17	14	15	41	41	28	22	317
Sault Ste. Marie, Mich.....	20	34	35	16	18	9	6	7	27	20	25	14	231
Green Bay, Wis.....	10	10	16	15	24	8	2	3	8	14	9	6	125
Milwaukee, Wis.....	18	27	25	23	14	2	2	5	9	10	8	7	149
Grand Haven, Mich.....	11	13	12	14	5	1	1	4	4	4	10	5	85
Chicago, Ill.....	20	18	33	22	22	15	6	6	12	18	23	21	218
Alpena, Mich.....	15	19	19	12	13	2	3	3	7	5	11	12	121
Port Huron, Mich.....	16	24	41	23	20	7	5	10	17	21	27	14	235

NOTE.—The months in which no wind-signal forms were prepared are estimated in both tables.

TABLE III.—Percentage of stormwinds from each direction for each station on the upper lakes, 1893 to 1897, five years.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
Duluth, Minn....	1	30	0	0	0	16	0	53
Marquette, Mich.....	4	0	0	11	32	29	4	20
Sault Ste. Marie, Mich.....	0	3	2	18	0	6	4	67
Green Bay, Wis.....	30	8	0	2	4	24	21	16
Milwaukee, Wis.....	6	7	4	12	4	30	21	16
Grand Haven, Mich.....	2	1	18	6	7	6	15	50
Chicago, Ill.....	6	11	8	18	22	29	10	5
Alpena, Mich.....	2	1	9	17	1	17	19	34
Port Huron, Mich.....	8	5	2	4	13	33	15	17

CAN LONG-RANGE WEATHER FORECASTS BE MADE WITH ANY DEGREE OF ACCURACY OR PROFIT?

A. B. CRANE, Pensacola, Fla.

Realizing the depth of the subject I have chosen to present to your notice, and my inability to cope scientifically with it, I beg to express the hope that the will be taken for the deed, and the few practical points enumerated herein, however imperfectly discussed or presented, be acceptable to this body and that sharp criticism be reduced to a minimum. My idea is to encourage the study of the subject more than to lay claim to theory.

The question is, can long range forecasts be made with any degree of accuracy or profit? My answer is, Yes, and No.

It seems to me, therefore, that it is, as yet, unnecessary to go out of our own atmosphere to look for coming changes in the weather. For years the most distinguished philosophers have made efforts to discover even periodic recurrence of weather changes of longer and more regular intervals than those between successive cyclonic centers, which are known to be of weekly or bi-weekly cycles; that is to say, in a general way a recurrence of similar conditions are known to exist for short periods, but no one can foretell the double cyclonic or anticyclonic period that controls or will control.

Yet there are many who believe the moon governs the weather: in fact, it is a popular belief, but nothing has been discovered to bear the test of comparison except in a slight and imperfect manner.

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I will, therefore, now take up that portion of long-range forecasting which I do believe in, or rather have reason to suspect is susceptible of improvement so that it can be put to practical use. This relates to cycles in weather.

There are geographic locations that receive almost regularly their quotas of weather and have striking climatic characteristics. We know that California has her wet and dry seasons; that the maximum rainfall occurs on the northern coast of Washington, amounting to slightly over 100 inches annually, and from that center gradually diminishes; that the reverse (almost and proportionately) is true of the Gulf and Atlantic sides, of course with few local exceptions: therefore, it is not a hard matter to look for rains in proportion and in season for those localities or districts.

The long-range forecaster can not well fail here, but he nevertheless relies upon, and has access to, the Weather Bureau records in formulating his prognostications.

Take another example: In a country where there are no mountains, there is little rain. The floating vapor which pervades the atmosphere and is drifted by the force of the winds requires the refrigerating tops of lofty mountains to gather and condense it, and send it back in showers or rains.

* * * * *

For generalized districts such as above mentioned we can readily understand and see why seasonal climatic changes occur. There are other localities also which show a marked periodicity or recurring types of weather. One point in particular I remember is Montgomery, Ala. For that place a graphic cross-section map was prepared, showing the daily, monthly, and yearly averages of temperature and precipitation, also their fluctuations. For several months the dates on this chart coincided with the actual normal conditions and variations closely enough to cause comment by the station force.

There may be other observers who have found similar results, and if so, it would be well for them to make a further study of the matter.

Now, to show that a very variable result may follow, and in about the same geographic division, I will state that I made a similar cross-section map for Pensacola, Fla., for the month of September, and could find no coinciding periodicities at all. The maximum temperature for that month was as liable to occur in the last part of the month as the first, or in the middle; the minimum showed a better agreement, however, and likely to occur sometime in the last decade, although it once occurred as early as the sixth of the month. The rainfall data shows no agreement whatever, save that the normal or average amount is 4.80 inches; that 11.54 inches fell in the year 1880 and 0.32 in 1883; that one, two, or three years in succession the rainfall would be either above or below the normal; and that the heaviest falls occurred scattered throughout the month. The wind data shows even a greater disparity in comparison; the mean hourly velocities vary considerably, the least being but 6.4 miles, in 1885, and the greatest, 10.3, in 1897. The maximum velocities ranged between 19 and 50 miles per hour, blowing from all directions, and

without any recognizable date or period in the month. The only definite sequence, then, was that the lowest temperature of the month might be looked for in the last decade.

* * * * *

By tabulating the data it will be found that, in a general way, storms of considerable severity usually occur on the Gulf and Atlantic coasts from March 1 to 31, and also in the autumn anywhere from the middle of July to October 1. This much meteorologists know and predict, and I refer to the forecasts made for the Hydrographic Pilot Charts of the North Atlantic, but no one can positively assert, or predict, that such and such will occur on such and such dates a year, or even a month, in advance. * * * Again, one may predict that, in the event of a large deficiency in rainfall for one season, that deficiency will be made up or counterbalanced sooner or later, although a deficiency may exist for longer than one or two seasons. In fact, such was the case at Pensacola last year. The deficiency began in April continuing throughout with a shortage of 16.40 inches at the end of December; even during the next year there was a general scarcity of rain up to the first week in August, when rains set in and a total of 18.58 inches occurred, breaking the record for the month, and to a large extent counterbalancing the deficiency. I feel confident that another wet spell will set in during the fall and early winter which will compensate, if not run over. But I can not say at just what time or dates it will occur. * * * The wisest long-range forecaster can not say just when the counter action will take place.

* * * * *

On one occasion I remember, a believer in the romancers called at my office for some information regarding the weather outlook. I gave it to him, the forecast happening to be for fair weather. "Why," he said, "that's funny; Mr. So and So, the weather prophet, says rain." "Well," I replied, "the funny part is that you believe in the long-range prophet." In this particular case, as in several others, I purchased the prophet's book, and sure enough there it was in plain English calling for rain on that particular day, when as a matter of fact the weather and day were as fine as could be wished for. The person in question, at my solicitation, turned back to former predictions, and together we carefully examined the records to verify this prophet's handiwork, much to the chagrin of the unknowing one, for he could scarcely find a day on which the conditions agreed with the forecast.

That gentleman left the office a wiser man, and with a better understanding of the works of long rangers, as well as a higher opinion of the Weather Bureau. From several verifications of this class of forecasts I have been unable, with liberal construction and marking, to find any that run over 40 to 60 per cent in value, and oftentimes not that high. This sort of work is worse than useless, and utterly impracticable for business purposes, to say nothing of the disadvantage it is, or may be, to business people, health seekers, builders, and pleasure parties. A uniform standing forecast of fair weather and stationary temperature will yield better results, or at least give a percentage of nearly 75, and not be so harmful.

Now, we come to another test question. There is no going against record and absolute fact. As an example I will cite that severe win-

ters, or rather freezes, in the State of Florida occurred in the following years: 1747, 1766, 1774, 1799, 1828, 1835, 1850, 1857, 1880, 1884, 1886, 1894-95, and that the best any one can make of these figures is that there appears to be seventeen years on an average between successive freezes, but note the disparity between the years in the whole time, it can scarcely be made into or called a cycle; the shortest interval is four years, and the longest twenty-nine years. Where is the long-range forecaster, or "prophet" if you will, that can safely say a year in advance, when the State of Florida will receive her next baptism of frigidity with its disastrous results.

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Science is defined as consisting simply of the systematic arrangement of facts, and more facts are needed before the artist, however energetic or skilful, can unfold that intricate study, long-range weather predictions.

THE WEATHER AS A TOPIC OF CONVERSATION.

A. S. BRENDLE, Schaefferstown, Pa.

I have never had much patience with that quite numerous class of critics who are in the habit of adverting facetiously to the keen interest manifested in the weather by many people in farming communities, as though it were quite ludicrous for any one to select as a topic for conversation the present and prospective effects of sunshine and rain, heat and cold, wind and calm. The farmer, it seems to me, has as much right as anyone to be interested in what pertains to his own vocation in life. The farmer knows best why it is that he is interested in the weather. It is inconceivable that he should be indifferent to what lies so close to his well-being. Whether the season will afford a proper proportion of heat and moisture to mature his crops is a question of success or failure with him. It is essential to his prosperity that there should be neither excessive rain nor hurtful drought. Consequently, who can blame him if, with anxious face, he often scans the skies, or if he chooses to regard the weather as a good topic for conversation. I, for one, can see nothing to condemn in so reasonable a practice. The most intelligent men in every country believe that it is worth while for the National Government to employ specialists carefully to study the weather indications and publish forecasts for the benefit of the people at large. It is right that the Government should do this, for it concerns the welfare of the whole country. Whether we are willing to admit it or not, we are all more or less interested in the weather; and it is certainly no laughing matter if people see fit to discuss weather facts or probabilities.

Some one has laid down the canon of conversation, that people should converse of what they understand best or know most about, of course not to the exclusion of everything else, but within reasonable limits. If that canon is sound, and it rests on good common sense, we must justify the farmer when, even in the social circle, he speaks by preference of the weather and his crops. And who will say that it is not as edifying to practical mortals to discuss the weather as any other topic in the whole range of human contemplation? The merits or demerits of the latest work of fiction or of the most approved system of metaphysics are trivial questions as com-

pared with one which involves the very existence of the whole human family.

The most learned investigator of nature can not consider it beneath his dignity or unworthy of his attention to study the laws that in their ever-varying combinations bring about the various meteorological conditions and changes. Those who think that the subject is only worthy of the rustic and the boor are miserably mistaken, and all their ill-timed jibes and flings recoil upon themselves.

The subject has its poetic side, too. The phases of the weather represent the varying moods of Nature, the mother of us all. She smiles in the genial sunshine and weeps in the summer rain; she whispers in the gentle zephyr and threatens in the lightning's flash; her frown is in the thunder-cloud, and her benediction in the sparkling dew drop. To be indifferent to the weather is to be indifferent to the moods of Nature herself.

DISTRIBUTION OF FORECASTS BY MAIL.

P. F. LYONS, St. Paul, Minn.

In compliance with a circular letter from the Climate and Crop Division of the Weather Bureau, dated July 9, 1897, the following method of locally distributing unaddressed cards, weather forecasts, and maps by mail was introduced at this station, August 9, 1897, and extended February 10, 1898, so as to include the weather maps.

The initial arrangements with the local postal officials consisted in preparing lists in triplicate of the addresses in the respective letter-carrier routes, of those entitled to service, and supplying two copies of each to the superintendent of carriers, who in turn supplied each carrier concerned with one, giving necessary instructions as to its use, the superintendent retaining the others for reference and use in case of confusion or loss of those in the possession of the carriers; the third set was filed at the station, and on it the additions, transfers, or other changes that may be made by Postal or Weather Bureau officials are duly noted.

The postmaster at first thought that, in order to comply with law, it would be necessary to put a number on each unaddressed card corresponding to the carrier's number who was to deliver it, and then have all deposited in the mail box for assortment, the same as ordinary mail. I concluded that but little labor in preparation of cards and no time in their delivery would be saved in that way; he next agreed to try the method of putting the cards intended for the respective carriers in bunches, and putting a number on the outside one corresponding to that of the carrier who was to deliver it, and then have all deposited in the mail box for assortment; but even then there was some time lost, for the matter had to be reassorted, or had to go through other hands before reaching the carriers; finally we arranged to have the packages transferred direct from the Weather Bureau to the carriers' room, in which is a large set of pigeon holes or carriers' boxes, each of which has a number corresponding to that of the carrier whose package it is intended to hold. The packages of cards are arranged at the Weather Bureau office, and taken directly to the carriers' boxes by our station force almost invariably

about 10 a. m., or in ample time for delivery through the business portion of the city before 12 noon of each day. By the old method, the delivery could not possibly be made before 2 or 3 p. m. of each day.

With the view of further reducing time and labor, I suggested to the superintendent of carriers that all cards and maps be made up in a single bunch, and then taken by the station force to a place in the post-office designated expressly for them, and that each carrier, as he prepares to start over his route, go to the designated place and help himself to the number required; but the answer was, "that would be contrary to rules or regulations," and could not be agreed to.

Suggestions.—Could not such rules or regulations be modified by the Post Office Department, at request of the Department of Agriculture or other officials empowered to act, so that the suggestion, or something similar made in the preceding paragraph, may be applied to the mail matter in question; but there may be objections on the ground that, where a carrier has a large number of addresses on his list, it would tax his time, etc., to count out the necessary number. Very well, grant that; but there are a large number of carriers whose lists call for but from one to five cards or maps, and it seems that it would be no extra trouble to them to go to the common pile where, no doubt, they would find the cards or maps placed as proposed and help themselves.

There are 67 postal carrier routes over which cards or maps are distributed from this station, consequently, that number of packages must be prepared and put in place at the post office for distribution daily; but the above statement applies only to the card forecasts; there is a second delivery of maps, but of which no carrier delivers more than three at a time, and in such cases surely it ought to be as easy for him to help himself from the pile as to get the maps from special boxes.

UTILITY OF HYGROMETRIC OBSERVATIONS.

ARTHUR PENNELL, M. E., Kansas City, Mo., and Prof. H. A. HASEN, Washington, D. C.

Mr. PENNELL. I have been investigating, for the last two years or more, methods for utilizing the hygrometric properties of the atmosphere for condensing exhaust steam, ammonia, etc., in localities where water is either scarce or expensive.

In obtaining the necessary data, the United States Weather Bureau has been my principal source of supply, and must be so to others engaged in similar lines of research.

In many manufacturing lines, an intelligent use of this hygrometric data would show some quite surprising economical results. For example, in the meat-packing business. The carcasses, after being dressed on the killing floor, are run into chill-rooms to have the animal heat abstracted and the temperature reduced to about 38° F., or below this point by artificial refrigeration. This operation entails a shrinkage averaging 2 per cent of the weight. This is due to the evaporation from the meat of that weight of moisture.

As now carried on, each 1,000 pounds of beef, for example, gives off 38,000 thermal units. The above-mentioned moisture congeals on the coils of the refrigerating plant in the shape of hoar frost and has to be swept away from time to time.

Were the meat, on its way to the chill-room, to travel slowly down an alley up which a strong draft of air, at the local average temperature of 55° F. and a dew-point of 44° F. was passing, the condensed moisture above mentioned would evaporate at the expense of the animal heat and be carried off into the atmosphere, thus, of itself, reducing the temperature of the meat to about 60° .

The meat, thus cooled down, would, on reaching the chill-room, only require about 16,000 thermal units to reduce its temperature to 37° . Thus, the amount of artificial refrigeration needed would be only about 42 per cent of that which is now required.

Even in hot, humid weather in summer, which is the most disadvantageous, the required percentage of artificial cooling would not rise above 80 per cent of that now required, while in cooler weather it would sink to zero. In order to safely accomplish this economy, the operator would have to know the temperature and dew-point of the atmosphere, and regulate the time of exposure and volume of draft accordingly.

In my own particular line I cool warm water by its own partial evaporation into the atmosphere, and utilize the cold for refrigerating plants, manufacture of ice, cold storage, etc.

In order to congeal water, it is very certain that the heat it contains must be abstracted from it and disposed of by some natural process, practicable even in the hottest summer weather. This is generally effected by pumping large quantities of water out of wells at an average temperature of probably 60° and passing it over ammonia condensers, thereby heating it to, say, 90° , and then running it off to waste. Each pound of water takes up 30 thermal units on its trip. A ton of refrigeration calls for 284,000 such thermal units. Consequently, at least 9,464 pounds of water must be pumped for each of refrigeration. In practice about 50 per cent more is required.

There are many places where refrigeration is desired and where water is either scarce or expensive. In such cases recourse must be had to atmospheric evaporation. All the different devices to effect this, my own among the number, work on precisely the same principle that a splash of water on a hot pavement shortly evaporates into air at the expense of the heat in the pavement. The hotter the pavement the quicker the action; also, the drier the air and brisker the breeze the quicker the action.

I use a tower, galvanized-iron clothing, and an iron skeleton, into the lower part of which the warm water is driven in a very fine spray from the center. The spray fills the lower part of the tower, up which a current of air is passing, either induced by natural draft or forced by a fan. The spray consists of very minute globules, the surface of which vaporize into the air at the expense of the heat of their interior. The spray strikes the periphery of the tower, trickles down, and falls into a catch-basin below, and can thus be used over and over again.

In designing such a tower, it is necessary to know the highest temperature the atmospheric dew-point ever attains in the locality and the temperature by the dry-bulb thermometer when that maximum dew-point occurs. The volume of such air required to reduce the temperature of some given weight of warm water to, say, 10° above the dew-point can then be determined, and the tower designed accordingly.

in the middle had been opened, and that coal hole was belching forth fire and smoke from the furnace beneath. In the furnace appeared the head and shoulders of our late lamented forecast official. In his left hand he held a sheet of asbestos, and in his right a piece of charcoal, and he had just written a forecast of a cold wave for "Hell and vicinity." Now, here is where the unfeeling, unsympathetic editor wreaked vengeance on the Weather Bureau. He said: "P. S.—This forecast of a cold wave for Hell and vicinity is just as likely to be verified as were any of those made by the deceased for this city."

Now, gentlemen, the press is a most important factor in the work of the Weather Bureau. How could we reach the great public without the dissemination of our information through the press? It has been my experience, for many years, that the press is inclined to be a little more than fair with the officials of the Weather Bureau. It is inclined to be a little more than fair with every public official. There may be isolated exceptions, but a man should not be too sensitive to criticism. Every public official should feel that it is legitimate for the newspapers to criticize his public actions. It is by that criticism that the public service is improved and the public welfare conserved. I would say to you, without digressing too much, that you should not take offense when the newspapers of your vicinity have a little fun with you.

Gentlemen, we have with us to-night one of the most distinguished editors of the United States—a man who has made his power for good and his influence for purity in public life and for honesty in the administration of public office felt throughout the length and breadth of this land. I never saw him until about six weeks ago when he came to Washington to assist in arranging for this grand Peace Jubilee, but I knew him, and we all knew him by reputation. I have the pleasure of introducing to you the Hon. Edward Rosewater, editor of the Omaha Bee.

MR. ROSEWATER. MR. TOASTMASTER AND GENTLEMEN OF THE WEATHER BUREAU: It was perhaps a rather singular freak on the part of your toastmaster to ask me to turn the searchlight of publicity on the weather service and the Weather Bureau, and I realize that the men who deal in futures in that Bureau will feel a little perplexed as to what is coming. Before we enter into a discussion of futures, however, let me digress a little bit to the past. I was the first Weather Bureau observer west of the Missouri River [applause]. Away back in '63 I was requested by Professor Henry of the Smithsonian, when I became located here at Omaha, to make a report from time to time on the weather conditions between Omaha and Salt Lake City. Well, there is nothing remarkable in that, particularly, for I was manager of the Pacific Telegraph [applause] and I had observations made and recorded every day at Omaha, at Julesburg, at Fort Laramie, Fort Bridger, and Salt Lake City; and these were telegraphically reported at given hours, three times a day, and recorded in a book which I kept, right here in Omaha.

Let me digress a little further, perhaps, and give you some facts regarding the foundation of your Bureau. The Weather Bureau, was, of course, the offspring of the Signal Service and the Signal Service was the offspring of the War of the Rebellion. During that war the

inspection the size of oval that can be best drawn from the figures.

Such wave crests have been drawn for more than two months, and have already shown that we have here a most powerful means of studying the origin and progress of such waves. For example, it has been found that almost invariably the wave of moisture has precedence over that of temperature and pressure, and that the pressure wave lags considerably behind both the others. This is almost a startling corroboration of the facts already brought out as to the movement of moisture, temperature, and pressure on Mount Washington; that is to say, a wave of high temperature accompanies a low-pressure wave, but the change to a lower temperature occurs first in the upper air and is thence transferred to the earth. It would also appear that the positions of these wave crests will enable us ultimately to determine the direction in which a high or low, for example, will move in the next twelve hours. If the last suggestion proves true, this will become a very important method of study, as all will readily recognize.

WIND VANES.

C. P. CROWK, Cape Henry, Va.

The vanes now in use are very large and heavy, and though they may work fairly well in strong winds when first put up, they are not sensitive enough in light winds, and their great weight develops so much friction that considerable force must be exerted to turn the arrow. The weight of the long and heavy vane rod is added to the mass of the vane of which it is really a part. Now, as friction, either rolling or sliding, is directly proportional to the pressure of the two surfaces, it is evident that the vane itself should be made as much lighter, and the vane rod as much smaller and shorter as consistent with utility.

As to the form and mechanism of the most suitable vane, it is suggested that experiments be made with the Weather Bureau anemometer by taking off the cups and arms and substituting an aluminum arrow, to be not heavier than the arms and cups. The dial case could be made use of, perhaps, as a connection box. It is, at any rate, believed that the connection box should be as close to the vane as the dial is to the cross arms supporting the cups.

But one objection to the light vane can be thought of. It may lack the steadiness of a large one, but from a few crude tests it is believed that slight but constant vibration of a small, light vane will simply tend to keep broken any adhesions that might result from its remaining too long in one position. There would be as little friction as in the anemometer.

This communication is no more than an introduction to the subject of improvement in wind vanes. I have neither facilities nor the time for the necessary investigation with attendant experiments.

In conclusion, it is desired to invite attention to Professor Abbe's *Treatise on Meteorological Apparatus and Methods*, pp. 188 and 189, and particularly to the paragraphs from which the following quotations are taken:

It is obviously unphilosophical to overcome this difficulty [oscillation] by adding to the inertia of the vane and by retarding it with an overwhelming amount of friction, which varies from day to day, and which is greater at the

Dr. BENJAMIN. I am very glad to avail myself of the opportunity of saying a few words concerning the beginning of systematic work in meteorology by the Smithsonian Institution.

It is just a little more than a half century since the Smithsonian Institution came into formal existence, and at that time the beginnings of the science of meteorology were apparent. The brilliant genius of Espy was making itself felt in various parts of the country; the patient Loomis was considering the subject in his careful way; and Redfield, more practical than the others, saw commercial benefits to be derived by collecting data about the weather. It is true, however, that even before this, the regular accumulation of meteorological observations had been undertaken from time to time under the direction of the War Department and also by the Navy Department, but they had not been persistent.

Professor Henry, the first Secretary of the Smithsonian Institution, in looking about for subjects with which to carry out in the best possible manner the wishes of the founder of the new institution established for the purpose of increasing and diffusing knowledge, was quick to recognize the value of giving information to the public in regard to the weather. Men of science from many localities throughout the country were invited to cooperate by making meteorological observations. These were sent to Washington and there placed in the hands of Professor Coffin, of Easton, who undertook their computation. The aid of the various telegraph companies was solicited and obtained. A large map was set up in one of the halls of the Smithsonian building, and every day, at a certain hour, facts of the weather as received were indicated on this map by means of suitable markers. In this way the first daily weather map came into existence. With the Civil War came a partial interruption of the work, chiefly in consequence of the extraordinary demands on the telegraphic service. After the war the transfer of the work to the War Department took place, and later it passed to the charge of the Department of Agriculture. But interest in meteorology did not cease in the Smithsonian Institution with the transfers just mentioned. Our present Secretary, Dr. Langley, realizing that the time must soon come when present means of transportation would be inadequate, has devoted much of his thought to studies connected with the problem of aerial navigation, and among these none has received greater recognition than those that pertain to the force of the winds.

Before taking my seat I want to say that some of us have grown to believe a good deal in Civil Service, and if, as certain of our politicians and newspapers would have us believe, that system of promotion by merit should be abolished, then I would observe that when that time comes, it will be impossible to secure for public office men who have risen from the ranks such as the present Chief of the Weather Bureau. We believe that he is a splendid illustration of the right man in the right place, and his fitness for his present appointment is the result of having demonstrated his capacity in subordinate affairs.

Professor MOORE. Just at this point, there is one matter to which I wish to refer, and that is the magnificent nonpartisanship of the present Secretary of Agriculture. In recommending and securing from

Congress legislation to extend the weather service into the arid and subarid regions of the West, into the cotton regions of the South, and into the West Indies, there has been no sectionalism in his policy. He is a Republican Secretary of Agriculture, and every one of those additional stations, except one, has gone into Democratic States. This is not a political Bureau [applause]. I say this without any disparagement to politics, because I believe there is not a man now looking into my face who does not value the elective franchise that is given to every citizen in America, and who will not freely and impartially exercise that franchise. But in extending the benefits of the weather service, the present Secretary of Agriculture, the Honorable James Wilson, and his assistant, Colonel Brigham, who presides in his absence, recognize that the weather service is here to serve all interests, without regard to politics. Gentlemen here have paid me several compliments as the Chief of this greatest of all meteorological services, but I want to say to them that my power is derived entirely from the Secretary of Agriculture and his assistant, and without their support I could not hold my office a minute. The credit for the work we are doing to-day belongs to them, I am simply their executive.

ERRATUM.

In the fifth line of the first paragraph on page 173, "Hon. William Pitt Kellogg" should read "Hon. Stephen B. Packard."

which occurs is within 4° of that forecast, eleven (79 per cent) of fourteen warnings of 1895-96 were verified at Galveston and thirteen (87 per cent) of fifteen issued for the territory 50 to 100 miles from Galveston were verified by taking the lowest temperature recorded in that section; all three (100 per cent) of the warnings of 1896-97 were verified both at Galveston and 50 to 100 miles from Galveston; nine (82 per cent) of the eleven warnings issued during the winter of 1897-98 were verified at Galveston and all except one (91 per cent) were verified by the lowest temperature which occurred 50 to 100 miles from Galveston.

The public is quick to appreciate efforts on the part of the Weather Bureau to supply information of the character desired as well as to make improvement in the forecasts. Those interested lose no time in taking advantage of any class of warnings which they can utilize. The truck growers when they feel certain that they will be promptly warned twelve to thirty-six hours in advance of approaching injurious temperatures, plant their fields with a view to protecting their crops when advised by us. In this section, where only occasional light freezes occur, and, as a rule, protection is practicable throughout the winter, vegetable and berry crops are cultivated during the winter months for shipment to northern markets and toward the close of the winter the most tender varieties of plants are pushed under protection so that this section now furnishes the earliest vegetables to northern markets.

The sugar planters put in larger crops of cane, and cut only as used by the mills when they feel sure that they will receive definite warnings far enough in advance to enable them to cut and windrow their cane before it is damaged by freezes. Every additional day that cane can be left standing in the fields improves the product, hence the great value of timely warnings. Besides these features the ability to grind as fast as cut from the fields results in a large saving to the producers. Through the warnings of the approach of injurious temperatures planters can take the risk of drawing the earth from the cane early in the season, and let the sun warm the roots to start an early growth. If injurious temperatures are forecast the cane is covered and protected and then uncovered again, as soon as favorable weather returns, without materially retarding its growth.

During periods of critical temperatures the local office of the Weather Bureau at Galveston is constantly in telephonic communication with those who have interests to protect, and especially with some part of the sugar and trucking region, by means of the long-distance telephone. The time of one man is frequently required all day at the telephone answering calls. The demand for information, over the long-distance telephone, from places outside of Galveston has become so great that the telephone company has placed a long-distance telephone in the office of the Weather Bureau at this place for the benefit of their patrons in other portions of the State who use the telephone, at their own expense, in communicating with this office. This is cited as indicating the interest in the warnings and the vigilance with which planters seek definite information.

Speaking for the southeastern portion of Texas I do not believe that it would be putting it too strongly to say that the general public would be as much inconvenienced without the Weather Bureau as they would be without the post office.

Regarding the utility of special temperature forecasts I desire to say that, while it does not appear essential that forecasts of probable temperatures be made for entire districts, a material improvement would result by issuing special forecasts giving expected temperatures for all localities where interests such as sugar cane and early truck growing are extensively engaged in. Such warnings can be utilized to the greatest advantage in the semitropical sections near the Gulf coast and in portions of California, where products can frequently be kept growing unprotected until January and by occasional protection throughout the winter. These warnings will also prove advantageous in all sections where extensive gardening for market is commenced early in the season, for damage often results from temperatures near freezing when there is no frost formation.

It was my intention to have given in this paper a description of the weather types which give injurious temperatures near the Texas coast, and the deductions followed in forecasting probable temperatures, but find that it must be deferred to some future time when I will prepare a separate paper on that subject.

Special temperature forecasts made at Galveston, Tex., for the district within 100 miles of that place, for the benefit of sugar planters and truck growers.

WINTER OF 1895-96.

Date.	Temperatures forecast for following day at—		Temperatures which occurred on the following day at—				Difference between temperatures recorded and those forecast.*	
	Galveston.	50 to 100 miles from Galveston.	Galveston.	Houston.	Stafford.	Columbia.	Galveston.	Lowest 50 to 100 miles from Galveston.
1895.	°	°	°	°	°	°	°	°
November 25 ..	37	32	36.6	Frost.	35	31	— 0.4	— 4.0
November 26 ..	34	28 to 25	37.0	Frost.	35	32	+ 3.0	+ 3.0
December 2 ..	36	30 to 28	39.4	30.1	27	28	+ 3.4	— 1.0
December 3 ..	36	32 to 28	42.2	36.0	32	31	+ 4.2	+ 3.0
December 4 ..	32	28	40.0	29.0	29	29	+ 8.0	+ 1.0
December 31 ..	30-27	24 to 20	31.7	32.0	28	32	+ 1.7	+ 8.0
January 3 ..	36	27	39.2	39.7	35	28	+ 3.2	— 2.0
January 4 ..	36	30 to 27	46.0	36.8	38	32	+ 8.0	+ 5.0
January 23 ..	42	34	Frost.	37.9	34	36	+ 1.8	0.0
January 24 ..	40	30	38.7	37.0	34	39	— 1.8	+ 4.0
February 7 ..	36	36	Frost.	37.5	38	40	— 3.0	— 3.0
February 8 ..	39	33	44.0	38.0	30	36	+ 5.0	— 3.0
February 14 ..	40-36	35 to 32	58.8	54.0	50	50	+18.8	+15.0
March 4 ..	44	37	45.6	43.0	40	43	+ 1.6	+ 3.0
March 18 ..	44	Frost.	45.5	37.8	Ice.	Frost.	+ 1.5	— 2.0
March 19 ..	44	36	45.5	37.8	34	37.5		
March 20 ..		Frost.						

* The plus (+) and minus (—) signs indicate whether the temperatures were above or below those predicted.

Temperature forecasts made at Galveston, Tex., for territory within 100 miles of that place, for the benefit of sugar and trucking interests.

WINTER OF 1896-97.

Date.	Temperatures forecast for following day at—		Temperatures which occurred on the following day at—					Difference between temperatures recorded and those forecast.*	
	Galveston.	50 to 100 miles from Galveston.	Galveston.	Houston.	Stafford.	Columbia.	Brenham.	Galveston.	Lowest 50 to 100 miles from Galveston.
1896.									
Nov. 27.	°	°	°	°	°	°	°	°	°
Nov. 28.	38	30	40.7	35.2	36.0	36.0	30.0	+2.7	0.0
Nov. 29.	34	28	34.7	35.5	35.0	33.0	33.0	+0.7	+4.0
1897.									
Jan. 25.	27	22	27.0	25.0	18.0	24.0		0.0	-4.0
Jan. 26.									

WINTER OF 1897-98.

1897.									
Dec. 2.	40	32	37.5	33.0	32.0	36.0	30.0	-2.5	-2.0
Dec. 3.									
Dec. 4.	30	24	30.0	27.0	26.0	27.0	23.5	0.0	-0.5
Dec. 16.	38	31							
Dec. 17.			44.9	39.2	37.0	39.0	31.0	+6.9	0.0
1898.									
Jan. 15.	40	32	Frost.	Frost.	Frost.				
Jan. 16.			44.0	37.0	32.0	32.0	34.0	+4.0	0.0
Jan. 25.	36	29							
Jan. 26.			43.2	39.5	37.0	40.0	35.0	+7.2	+6.0
Jan. 28.	40	32		Frost.	Frost.	Frost.			
Jan. 27.			42.8	39.2	36.0	35.0	36.0	+2.8	+3.0
Feb. 2.	39	31							
Feb. 3.			39.0	35.0	32.0	33.0	28.0	0.0	-3.0
Feb. 5.	42	34							
Feb. 6.			48.2	41.2	36.0	34.0	36.0	+6.2	0.0
Feb. 20.	43	34							
Feb. 21.			41.3	36.5	33.0	32.0	33.0	-1.7	-2.0
Mar. 2.	42	33							
Mar. 3.			42.0	41.0	37.0	40.0	36.0	0.0	+3.0
Mar. 23.	40	32							
Mar. 24.			43.8	39.0	37.0	39.0	35.0	+3.8	+3.0

*The plus (+) and minus (-) signs indicate whether the temperatures were above or below those predicted.

AN OFFICIAL OF THE WEATHER BUREAU: HIS DUTIES AND QUALIFICATIONS.

B. S. PAGUE, Portland, Oreg.

The following is submitted as the personal opinion of one who has had nearly eighteen years' service in the meteorological bureau of the United States:

In newspapers, periodicals and books, except in those of a scientific or semiscientific character, it is always found that the Weather Bureau official is mentioned as "The Weather Man," or in terms of like import, at once assuming a humorous tendency. For the past ten years, efforts have been made to eliminate this lighter vein from all publications. Like poison once taken, antidotes work slowly though surely, so that the humorous is only slowly passing away. The Weather Bureau official has been laboring for years to place his work upon a sound and dignified basis, endeavoring to make the work done

each day so valuable that its importance and merit would command the respect of the public. Hence, his chief characteristic is his desire to be of value to the people. The observations and reports are each so important that seriousness enters into his work, even to the most minute detail; promptness, careful attention and accuracy mark the work of the Weather Bureau official. To succeed in anything, whether in manual labor, or in the most abstract problem of science, it is necessary that the individual possess ability, energy, liberal views and a discerning mind. To succeed in a scientific pursuit, and especially in one that is viewed with skepticism by the masses, requires a most fertile brain, sound judgment and accurate deduction.

The qualifications of a man are often difficult to determine. A powerful writer is one having knowledge, logic, rhetoric, thought, and language constantly at his disposal. A successful orator in addition to the preceding must have a physical force and personal presence that commands the attention and respect of his hearers, a well modulated voice and the power to emphasize the important points of his discourse. An official in the Weather Bureau may possess all these, yet not succeed in his work. The Weather Bureau requires so many and varied duties that the special qualifications are at times difficult to determine, but when once found are sure to be recognized.

Offices located in rural communities, where the official performs only the routine duties required are not always made as valuable as they should be; it may be difficult to determine how offices so located may increase their importance, how the official can make himself of value to the community, and how secure the respect and good will of the people in his work; yet this can be done, if the individual is devoted to his work, if he has a love for his duty, if he is working for the good of the Bureau and not for his own material good or pleasure. In cities the scale of work is so large that few are found qualified to conduct it so that the greatest possible good is accomplished. The practical work of the Weather Bureau is being demonstrated daily, and hence the stations of the Bureau are growing in importance; the individual must grow or else fall behind in the procession of events. To keep pace with the development of the work of the Bureau requires active, intelligent men; men who are quick to grasp ideas and to put them into execution. The time is past when no forward move on the checker board of work can be made without the suggestion or sanction of the Central Office in Washington.

An official is charged with certain specific duties, but his instructions are general; the latitude given the subordinate is such that his ability may be developed and his work thereby become of greater value to his immediate community. The successful official associates with the people of the community in which he lives. He makes a study of their needs and moulds his work accordingly. If he lives in a dry region, he studies the water supply and endeavors to lay before the people the necessity for a certain course of action in order that the available climatic elements may be made as valuable as possible; if in a wet region, there are numerous features at his disposal that can be utilized with profit. In an agricultural, horticultural or stock region various interests can be served. In commercial communities a wide field is offered for successful work and equally as great opportunities are offered in marine communi-

ties so that no matter what the conditions may be surrounding an official, if he be mentally alert, he can increase the value of the work. Every office is primarily of equal importance; as the surroundings are increased, whether for commercial or industrial pursuits, so are the avenues for valuable work increased. He who is great in small things can be great in large affairs, so that growth is open to all, no matter what the local environments may be. Every office depends upon the other. No central office, state or national, can be successful in the work of the Weather Bureau without loyal support from every minor office, no matter how meagre its equipments are. Never was one cog-wheel more dependent upon others for its own motion than are the larger offices upon the smaller. The official in high rank is as dependent upon the lower in rank as the lower is dependent upon the higher.

These are some of the features found in the work of the Weather Bureau, and the one who possesses the qualifications to fully utilize the many and varying opportunities presented to him is the one who is, or will be, successful. The Weather Bureau official should be able to express himself in writing or speaking so as to command the respect of his readers or hearers. He must possess a pure character so as to have the moral respect of the people. He must work upon broad and liberal lines with the people in the community in which he resides. He must be a man of intelligence, of force of character; must possess in a high degree the attributes that are necessary to success in any and every important undertaking in life. He should study the people, visit their fairs and expositions, and be connected with the management of them; attend and take an active part in agricultural college institutes. Every gathering of agricultural and horticultural people should be attended by a Weather Bureau official. He should know the soil and climatic conditions and be able to discuss them intelligently. He should be in close touch with public schools and colleges, and especially with agricultural colleges and technical schools; interest the teachers and educators in his work; be connected with, and participate in, the work of scientific societies, and be closely related to the newspaper people and have the most cordial relations with them.

These are some of the qualifications most necessary to make the work of the Weather Bureau a success. The people must be educated to the value of and benefit arising from the work in which the official is engaged. When he has accomplished this, progress, advancement, and success will reward him. So far as possible the individual must not, *per se*, be prominent. The Weather Bureau should always be more prominent than the official. The Bureau lives while the official passes away, but as the Bureau rises in the estimation of the public, so will the official rise. The Bureau must be of value to the people, the official of value to the Bureau. The personal reputation and importance of the official depends upon his union with the Bureau and his faithfulness to it and to the people.

The Weather Bureau is in its infancy. It has a great future. The individual can not float above with the tide; he must stem the current, and, with the Bureau, by force of attainment, character, and steadfastness of purpose win success.

APPENDIX A.

On the evening of October 14 a banquet was given which was attended by members of the Convention and a number of guests, among whom were the Hon. Joseph H. Brigham, Assistant Secretary of Agriculture; Hon. John M. Thurston, United States Senate; Hon. D. H. Mercer, M. C.; Hon. William Pitt Kellogg, E. Rosewater, Esq., editor of the Omaha Bee; Sands Woodbridge, Esq., of the Omaha World-Herald, and others who, with the Weather Bureau officials, numbered about one hundred.

As the speeches at the close of the banquet were by men who have achieved distinction in public life, journalism, and other pursuits requiring the highest order of ability, it is deemed appropriate, as far as practicable, to give their remarks, as showing the estimate they place upon the value of the Bureau's work.

No provision was made for a stenographic report of the banquet speeches, and it is wholly due to the kindness and industry of Mr. Robert M. Reese, stenographer to the Honorable Secretary of Agriculture, and to his efficiency and thoughtfulness that it is possible to give the remarks of part of the speakers. Some excellent speeches, however, were not taken by the stenographer, a matter of regret, as those delivered by the Hon. D. H. Mercer, Prof. Cleveland Abbe, Hon. John R. Sage, Director B. S. Pague of the Oregon section, and others were able and interesting.

Professor Moore presided and spoke as follows:

GENTLEMEN OF THE WEATHER BUREAU AND HONORABLE GUESTS: Here, and over the broad areas stretching away 1,500 miles on either side of us, was founded a republic exemplifying the most sublime confidence in man. Others had built upon vested rights, traditions, or theories, but here for the first time was founded a system of government based upon the natural and inherent rights of man. Such a system of government gave the world its first ideals of liberty, reconciling authority with liberty, liberty with authority, and solving at once and for all time the great problem of human government. Now, what has been the result of the benign conditions of soil, climate, and government under which we exist? Why, we have been able to meet and hold our Weather Bureau Convention, midway between the great oceans, with the vast mineral wealth of the mountains towering on our west and the great fruitful plains on our east; to enjoy the society and the hospitality of a highly cultivated and thrifty people, where but a few years ago the virgin soil of the prairie was yet unbroken; to witness out here at the second edition of the White City, the material and physical manifestations of the agriculture, the arts, and the commerce of a people unequaled for their skill, their inventive

genius, and their energy by any other race or amalgamation of races throughout the world [applause].

What have been the results of these Divinely given conditions—these Divinely given physical, geographical, meteorological, and geological conditions? Here all Nature has conspired to make a great people, to build up a great civilization. Recently a great national crisis confronted us. But, gentlemen, the seeds of national virtue and patriotism planted at Lexington, Yorktown, and Lake Erie, watered and fertilized by the blood of Gettysburg and Appomattox, and nourished during the past thirty years by the invigorating sunshine of the most free and liberal education with which a people was ever blessed, have given to our armies in the field a sturdy and enlightened manhood which made Santiago possible, and which realized the magnificent victory of that grand old hero at Manila. What has been the result? Why, as Corporal Tanner recently said, "We have given to the world an eighth wonder; we have presented to the effete monarchy of Spain the grandest submarine navy the world ever saw!" [laughter]. We have shown, gentlemen, that the American people, notwithstanding the acrimony of their political discussions, have such sublime confidence in the wisdom, the patriotism, and the justice of the Christian statesman whom they have elected to preside over their destinies that all political parties will sustain him in the hour of the country's peril [loud applause].

But, gentlemen, we have grown rich, populous, and prosperous in the cultivation of the arts and sciences of the greatest of all countries, and to-day we are turning our eyes toward the sunny Tropics and toward the ethereal blue of the far away west in quest of other peoples upon whom we may stamp the impress of our institutions and the munificence of our American civilization.

The American people are adept in invention, in applying knowledge and science to the commerce and industries, not only of their own country, but of the world. And in no way is that aptitude better shown than in the meteorological service of the Department of Agriculture.

The great raisin industry of California testifies to the value of our warnings. The shippers of the perishable produce of the country, the marine interests of the Great Lakes and of the Atlantic Ocean, all testify in the most emphatic terms of the millions annually saved through the warnings of this meteorological institution. I listened to the president of one of the largest sections of the British Association for the Advancement of Science, at Toronto two years ago, and heard him declare that the United States Government was far in advance of all other governments in its meteorological knowledge and in applying that knowledge to practical affairs. I give a few of these facts for the benefit of those not familiar with our work.

Probably in no case within my range of vision, certainly in but few cases, is that citizenship I have just extolled better illustrated, or its possibilities better shown, than in the life and achievements of him who, simply as a farmer's lad, entered the service of his country, and by valor rose to the rank of colonel; who served his State in the State senate; who lately presided over one of the greatest organizations in this country—I mean the National Grange—and at a still later period was called into the cabinet councils of the greatest republic on earth. Gentlemen, I have the honor to intro-

duce to you the Assistant Secretary of Agriculture, the Hon. Joseph H. Brigham.

MR. BRIGHAM. GENTLEMEN OF THE WEATHER BUREAU AND OTHER DISTINGUISHED CITIZENS: I am very glad to have the privilege of meeting with you here to-night, and to be permitted to say a few words about the Department of Agriculture, a Department that exists to-day because of the earnest efforts, long continued, of farm organizations. I am familiar with every step that was taken for the creation of this Department. The work was done by plain, practical men, not for the purpose of furnishing soft places for politicians, not for the purpose of drawing a certain amount of money from the National Treasury. Their idea and purpose was to help the greatest and most important industry of our country, that of agriculture. They realized that a large per cent of our people must always labor in the field, must be directly connected with agriculture. They believed it to be important to dignify the calling of agriculture; they believed it important to teach the ambitious boy on the farm that there was room for the exercise of all his ability and energy in the field of agriculture; they believed it important to have a representative in the council chamber of the Chief Executive, where suggestions could be made in the interests of this great and indispensable industry, agriculture.

Having this object in view, they labored earnestly for many years to secure their desire. Very few people believed it possible when it was first agitated; even the agricultural press scouted the idea of having a Department of Agriculture. They seemed to think it was class legislation. Farmers did not so consider it; they understood that everybody was interested in cheapening the cost of bread, and that everybody had to rely upon the labor of those who toil in the fields; that when the farmers prosper, there is general prosperity, and that when times are hard on the farm they are hard everywhere. They understood this, and so they labored for the elevation of the Department, and their efforts were crowned with success. Now, it was necessary to have at the head of this Department a man who was in full sympathy with this purpose. I believe we have in the present Secretary of Agriculture a man whose whole soul and all his energy are directed to the purposes that they had in view, namely, of doing some useful work for agriculture. There are a good many people in the world who do not comprehend the importance of this industry. I want to say to you that the crop of a single year, if multiplied by twelve, would pay the national debt of every country in the world—*every country in the world!*—and many nations never expect to pay their debts. Three billion five hundred million dollars was the cash value of the crop of 1897. In the last year, we sent abroad, after supplying our own people, after feeding our own people as no other people in the world are fed, \$1,210,000,000 worth of our products. Not all of this came from the farm, but 70 per cent of it was from the farms of our country. Something over \$800,000,000 more than we bought from foreign countries have been exported in the last two years. If we can continue that for a few years, and I believe we can, with the able assistance of the Weather Bureau [applause], we may expect to see coming back to our country every bond and obligation held abroad, canceled and paid.

of Fahrenheit had then been in use but a few years; and, compared with the fine instruments now used for measuring temperature, the error due to imperfect mechanical construction was probably considerable. About one hundred years after the invention of the barometer, viz, in 1747, Benjamin Franklin, patriot, statesman, diplomat, and scientist, divined that certain storms had a rotary motion and that they progressed in a northeasterly direction. It was prophetic that these ideas should have come to him long before anyone had ever seen charts showing observations simultaneously taken at many stations. But, although his ideas in this respect were more important than his act of drawing the lightning from the clouds and identifying it with the electricity of the laboratory, yet his contemporaries thought little of his philosophy of storms and it was soon forgotten. It will be interesting to learn how he reached his conclusion as to the cyclonic or eddy-like structure of storms.

Franklin had arranged with a coworker at Boston to take observations of a lunar eclipse at the same time that he himself was taking readings of it at Philadelphia. Early on the evening of the eclipse an unusually severe northeast wind and rain storm set in at Philadelphia, and Franklin was unable to secure any observations. He reasoned that, as the wind blew fiercely from the northeast, the storm was of course coming from that direction, and that Boston must have experienced its ravages before Philadelphia. Reports indicated that the storm was widespread. What was the surprise of Franklin when, after the slow passage of the mail by coach, he heard from his friend in Boston that the night of the eclipse had been clear and favorable for observations, but that a terrific northeast wind and rain storm began early the following morning. He then sent out inquiries to surrounding stage stations and found that at all places southwest of Philadelphia the storm had begun earlier, and that the greater the distance the earlier the beginning, as compared with its advent in Philadelphia. Northeast of Philadelphia the time of the beginning of the storm had been later than at that city, the storm not reaching Boston until twelve hours after its commencement at Philadelphia.

In considering these facts a line of inductive reasoning brought Franklin to the conclusion that the wind always blows toward the center of the storm; that the northeast hurricane which Boston and Philadelphia had experienced was caused by the suction exercised by an advancing storm-eddy from the southwest, which drew the air rapidly from Boston toward Philadelphia, while the source of the attraction—the center of the storm-eddy—was yet a thousand miles to the southwest of the latter place; that the velocity of the northeast wind increased as the center of the storm-eddy advanced nearer and nearer from the southwest, until the wind reached the conditions of a hurricane; that the wind between Boston and Philadelphia

shifted, and came from the southwest after the center of the storm-eddy had passed over that region; and that the force of the wind gradually decreased as the center of attraction passed farther and farther away to the northeast.

Another man whose name is dear to the heart of every patriotic American conducted in conjunction with his friend, James Madison (afterward Bishop), a series of weather observations, which were begun in 1771 and continued during the stirring times of the Revolution. This was the sage of Monticello, Thomas Jefferson. Madison was near the sea, at the colonial capital, Williamsburg, Va.; Jefferson was at Monticello, 120 miles west. They took simultaneous observations for several years, until the British ransacked Madison's house and carried off his barometer.

Had the telegraph been in existence Jefferson and Madison would doubtless have conceived the idea of a national weather service, as they discovered by comparing observations that barometric and thermometric changes usually occurred at Monticello four or five hours before they did at Williamsburg.

Contrary to the statements which I believe have been made by some historians, the Fourth of July, 1776, was a cool day; for the great author of the Declaration of Independence did not fail to read his thermometer in Philadelphia on that day. An examination of his papers in the State Department, made by an official of the Weather Bureau, proved that he took several readings, viz, 6 a. m., 68°; 9 a. m., 72½°; 1 p. m., 76°; 9 p. m., 73½°. These early observers did not escape the one unfailing vagary that even at this late period haunts the mind by day and induces feverish dreams by night in nearly every person who has not made a study of meteorological data; for in 1781 Jefferson said:

A change in climate is taking place very sensibly. Both heats and colds are becoming much more moderate within the memory of even the middle-aged. Snows are less frequent and less deep. They do not often lie below the mountain more than one, two, or three days, and very rarely a week. The snows are remembered to have been formerly frequent, deep, and of long continuance. The elderly inform me that the earth used to be covered with snow about three months in every year.

But Jefferson and his neighbors were mistaken. Never during the period of authentic history has the snow covered the ground in Virginia for periods averaging three months per year for three years in succession. The old inhabitants of Jefferson's time were like those of to-day—they remembered only the abnormalities of the climate of twenty-five or fifty years before, and in comparing the unusual conditions of long ago with the average of the present they were deceived. I have known intelligent and truthful men publicly to declare that they *knew, from personal recollection*, that the climate of

their particular places of residence had changed since they were boys—that they had reliable landmarks to show that the streams were drying up, that the precipitation was growing less, and that the winters were becoming milder—notwithstanding the fact that carefully taken observations of temperature and rainfall for each day for the previous hundred years showed no alteration of climate at such places. Of course, wide variations, sometimes extending over periods of several years, had occurred; but a deficit at one time was made up by an excess at another. To be sure, changes must have taken place during geologic periods; but these have been so slow that it is doubtful whether man in his civilized state has occupied the earth long enough to discover an appreciable quantity. Quite accurate records of the opening of navigation in the rivers of Europe and of the time of vintages for five hundred years show no change in the average data of the first ten years as compared with the average of the last ten; and the date palm, the vine, and the fig tree flourish as luxuriantly to-day in Palestine as they did in the days of Moses. Dried plants have been taken from the mummy cases of the Pharaohs exactly similar to those now growing in the soil once trod by those ancient monarchs.

The matter of change of climate is very important to our subarid West, to the States whose normal rainfall is just enough to produce a profitable crop. Some years ago, when the tide of immigration was strong, there were several years of rather more than average rainfall in regions that theretofore had had little rainfall for profitable agriculture. These two conditions were accidentally coincident; but the fact probably gave rise to the theory that civilization brings an increase in precipitation. It was thought that the breaking of the virgin soil, making it more permeable, and thereby conserving the scant deposit of moisture; the planting of trees and the propagation of vegetation, by restricting the run off and by drawing up the moisture from below the surface of the ground through roots; the enormous quantities of aqueous vapor injected into the air by the combustion incident to a teeming population—had all combined to increase the rainfall and to render the subarid plains more responsive to the efforts of the husbandman. No one with even a spark of that fellow feeling which “makes us wondrous kind” can fail to regret that this theory is not founded upon fact. But a moment’s thought will indicate to the physicist that the volume of superincumbent air is so great, and its capacity for moisture so enormous, that the additional vapor of water evaporated as above described, great though it be, is ineffectual to change appreciably the amount of rainfall which nature beforehand had ordained should be precipitated.

The size of continental areas, the topography of the land surface, the proximity of large bodies of water, and the direction of the pre-

vailing winds, are all factors in determining the precipitation of a region; and it is probable that the feeble efforts of man will never be able materially to modify the result.

If the Rocky Mountains were eroded down to the height of the Appalachian chain, the vapor-laden winds from the Pacific would blow inland, and probably cause copious rainfall as far east as Colorado, western Kansas, and western Nebraska. But these are changes which can be accomplished only in long geologic periods.

During the first half of the nineteenth century—nearly a hundred years after Franklin's northeast rain storm—Redfield, Espy, Loomis, Henry, and other American scientists laboriously gathered by mail the data of storms after their passage, and demonstrated their principal motions to be much as Franklin had supposed. In 1855 Prof. Joseph Henry, Secretary of the Smithsonian Institution, constructed a daily weather map from observations collected by telegraph and nearly simultaneous. He did not publish his forecasts, but used his large wall map for the purpose of demonstrating the feasibility of organizing a Government weather service. If there were no other achievements to the credit of the grand institution founded in this country through the benevolence of the English philanthropist, James Smithson—who, by the way, never gazed upon our fair land—the work of the Smithsonian Institution in connection with practical meteorology should always accord it a warm place in the hearts of those who believe that the crowning achievements of science consist in giving to the world knowledge which results in the saving of human life, the amelioration of the sufferings of humanity, and the acceleration of the wheels of commerce and industry.

Although American scientists were the pioneers in discovering the progressive character of storms, and in demonstrating the practicability of weather services, the United States was only the fourth country to give legal autonomy to a weather service. Holland established a weather service, with telegraph reports and forecasts, in 1860; England followed, with a smaller service, in 1861; and France, in 1863. But none of these countries has an area, from which observations can be collected, great enough to give such a synoptic picture of storms as is necessary in the making of useful forecasts. It would require an international service, embracing all the countries of Europe, to equal ours in extent of the area covered and in the accuracy of its forecasts.

The vast region now included in the scope of the Weather Bureau system of observations embraces Canada and the Gulf of Mexico; the whole having an area extending two thousand miles north and south, three thousand miles east and west, and so fortunately located in the interest of the meteorologist as to include an important arc on the circumpolar thoroughfare of storms of the Northern Hemisphere.

Simultaneous observations, collected twice daily by telegraph from about two hundred stations, distributed throughout this great area, render it possible at several central offices, where all the reports are received, to present to the trained eye of the forecaster a wonderful panoramic picture of atmospheric conditions. Every twelve hours the kaleidoscope changes, and a new graphic picture of actual changes is shown. The movements of the storm centers and cold-wave areas are noted, and estimates made as to their probable course during the next twenty-four hours. Where else can the meteorologist find such an opportunity to study storms and atmospheric changes? The widely differing elevation, topography, temperature, humidity, and aridity of the broad region under observation offer unequalled conditions for the study of the mechanical phases of storm development and progression—so far as such can be profitably studied with observations taken only at the bottom of the ocean of air surrounding the earth. Our storms and cold waves can be studied during their inception at an average altitude of five thousand feet above sea level, under conditions of extreme aridity; they can be observed later, as they come down almost to sea level in the Mississippi Valley and reach a more humid atmosphere one thousand miles from the place of their birth; and, finally, they can be seen as they reach the extremely humid air of the Atlantic Ocean, fifteen hundred miles farther east.

The great winter storms which originate south of the Japanese Islands and cross the Pacific Ocean come under our vision as they successively surmount the formidable Rocky Mountains with but little diminution of energy, sweep across the continent with increasing force and heavy precipitation and within three days pass beyond our meteorological horizon at the Atlantic seaboard, to be heard from occasionally three days later as boreal ravagers of northern Europe.

The great anticyclones, or high-pressure areas, which constitute the American cold waves, drift into our territory from the Canadian northwest provinces and are studied under rapidly changing conditions during 3,000 miles of their course. The high-pressure eddy, with all the convectional principles of the cyclone reversed, may be said not to depend upon the land of its birth for the cold it brings; for a strong vortical and anticyclonic motion at the center is continually bringing down the cold air from above. In other words, our cold waves are not, as was once supposed, masses of heavy air chilled by flowing over the snow and ice fields of the Arctic Ocean and transported to our central valleys with such rapidity of translation as to retain much of their original frigidity.

In 1870 and for some years thereafter our forecasts and storm warnings were looked upon by the press and the people more as experiments than as serious statements. The newspapers especially were prone to comment facetiously on the forecasts, and many were

clamorous for the abolition of the service during the first years of its existence. There was some ground for the criticisms. We knew nearly as much about the mechanics of storms at that time as we do to-day; but we had not—by a daily watching of the inception, the development, and the progression of storms—trained a corps of expert forecasters such as now form a part of the staff of the Chief of the Weather Bureau, and from which he himself was graduated. After a time mariners began to note that danger signals were, in the great majority of cases, followed by heavy winds, and they reasoned that it were better to take precaution against forecast storms that never came than to be unprepared for those which did come.

It is a fact that many times, by the operation of forces not indicated by the surface readings, the barometer at the center of a storm begins to rise and the velocity of the whirling mass to decrease. In such cases the storm signals placed in advance of the storm center would fail to give the proper information. Again, the storm center may suddenly acquire a force not anticipated, or it may pursue a track considerably divergent from the normal for the location and season. In this case, also, the forecasts may warn some cities that fail to receive the effects of the storm. The staff of the Weather Bureau, which includes many able meteorologists, has not failed to make a study of the peculiarities of the several types of storms occurring in different localities during the various seasons of the year, their line of travel, and the force that they may be expected to attain. The comparative merits of those who by natural ability were best fitted correctly and quickly to correlate in their minds the conditions shown on a meteorological chart and to make accurate deductions therefrom as to the development, movement, and force of storms have been tested by competitive examinations. This line of study and competition has resulted in improved forecasts, so that mariners now universally heed the storm warnings, horticulturists and truck gardeners make ample provision against frost, and shippers of perishable produce give full credence to the cold-wave predictions. Of the many West Indian hurricanes which have swept our Atlantic seaboard from Florida to Maine during recent years not one has reached a single seaport without danger warnings having been sent well in advance of the storm, and no unnecessary warning has been issued. The result is that no disaster of consequence has occurred. Large owners of marine property estimate that one of these severe storms traversing our Atlantic coast in the absence of danger signals would leave not less than \$3,000,000 worth of wreckage. On two occasions a census was taken immediately after the passage of severe hurricanes to determine the value of property held in port by the danger warnings sent out in advance of the storms. In one case, the figure was placed at \$34,000,000; in the other, at

\$38,000,000. Of course this does not represent the value of property saved. It simply shows the value of property placed in positions of safety as a result of the danger signals and warning messages sent to masters. On January 1, 1898, an extensive cold wave swept from the Rocky Mountains eastward to the seaboard. Estimates secured from shippers in one hundred principal cities indicated that property valued at \$3,400,000 was saved as a direct result of the predictions sent out.

There is hardly a daily paper that does not publish weather forecasts in a prominent place, and there is scarcely a reader who fails to note the predictions. The utility of these forecasts to the agriculture, the commerce, and the industry of the country is so great that it may be interesting to note more in detail the methods by which observations are collected, forecasts made, and meteorologic information disseminated.

Our Weather Bureau maintains about two hundred regular meteorological stations, each in charge of a trained observer, advantageously located geographically for the taking of observations. The transmission of reports is accomplished with remarkable rapidity by means of an effective arrangement of telegraphic circuits. Observations from all parts of the United States and Canada, from the Atlantic to the Pacific, are collected at Washington within thirty minutes after the observers have read the station instruments and filed their observations. Synoptic charts are prepared in the central offices at Washington and Toronto, and at many of the large stations at which reports are received; and by 9 o'clock (seventy-fifth meridian time) the charts are complete. The chart of greatest value to the forecaster contains for each station the temperature, barometric pressure, wind direction and velocity, weather conditions—whether raining, snowing, cloudy, partly cloudy, or clear—and the amount of precipitation, if any. Lines, called "isobars," are drawn for each one-tenth of an inch of barometric pressure, bounding the areas over which the air is respectively lightest and heaviest. These areas are called "highs" and "lows"; but they are only relative terms, as on one map the highest pressure may be over two inches in excess of the lowest, while on the map of another day the difference may be less than one inch.

Several other charts are prepared in the forecast room of the Central Office at Washington, as follows: Temperature-change map, showing the maximum and minimum temperature at each station, with changes from the day before and changes from the normal; barometer-change map, showing twelve and twenty-four hour changes and changes from the normal; cloud map, indicating the character, nomenclature, quantity, and movement of clouds; and a map showing wet-bulb and dry-bulb temperatures, with differences between the two.

If the student of the weather maps will pay close attention to them each day, he will find that the highs and lows move across the country in almost regular succession. If the high be a decided one, it will cover a territory one or two thousand miles in width, the weather within its influence will be cold and clear, and the winds will have a general tendency spirally outward from the center in a direction corresponding to the movement of the hands of a watch. The low is the opposite of the high in almost all its characteristics. It is usually attended by clouds, rain or snow, and high winds. The winds within the influence of the low blow spirally inward in a direction contrary to those under the influence of the high. The lower the barometer and the steeper the gradient, the more rapid is the whirl. These are some of the characteristics of lows. Those of like class take nearly the same course, and produce about the same results; but they do not always move with the same rapidity. No exact rule in regard to them can be laid down. Empirical reasoning, and intimate association with the charts, day after day and year after year, in the main equip the successful forecaster for his important functions.

Just as the eddies in a river go whirling down stream, so are cold-wave eddies (highs) and rain-storm eddies (lows) carried eastward by the general movement of the upper atmosphere in the latitudes of the United States. It is important that the fundamental principles of these eddies be understood, since the weather changes experienced from day to day depend almost wholly upon the development and drift of these high-pressure and low-pressure eddies, or, as they are better known, highs and lows. The two eddies are easily distinguishable the one from the other; for, while traveling eastward in the same general direction, they rotate in opposite directions. The high-pressure eddy always follows in the track of the low-pressure eddy. In the high-pressure eddy—in which the air is cold and clear, and in which the degree of cold is nearly proportional to the rise of the barometer—the air is drawn downward near the center of the eddy, and forced outward in all directions from the center along the surface of the earth. This eddy at times is two thousand miles in diameter. In the low-pressure eddy—in which the air is warm, humid, and often rainy or snowy—the surface air is drawn inward from all directions toward the center. Thus, the alternate passage of highs and lows controls our weather conditions.

About six-sevenths of our low-pressure eddies move from the Rocky Mountains eastward. They vary from the gentle whirls to storms of considerable intensity. Their average diameter is about one thousand miles. The West Indian hurricane, which comes up from the Tropics and skirts along our Atlantic shore-line, has a diameter of rotation less than one-half that of the usual low-pressure eddy; but its velocity

of rotation is much greater. Many of these hurricanes have a diameter of only three or four hundred miles; but their velocity of rotation is very often one hundred miles per hour, although their rate of translation, as they move northeast along our coast, is seldom greater than thirty miles per hour.

Twenty-five years ago mariners on our Great Lakes and seaboard depended on their own weather lore to warn them of coming storms. Then, although the number of craft plying on our waters was much less than now, every severe storm that swept the Lakes or Atlantic coast left destruction and death in its wake, and for days afterward the dead were cast up by the receding waves, and the shores were lined with wreckage. Happily this need not now be the case, for the Weather Bureau of the Department of Agriculture is ever watching the changes of atmospheric conditions and giving the mariner warning of coming storms. Each observer telegraphs instantly to the Central Office whenever the instruments at his station show unusual agitation. By this means the inception of many storms is detected when the regular morning and evening reports fail to give notice of their origin.

Some idea of the vast interests floating in Atlantic ports may be had when it is stated that 5,828 transatlantic steamers, with an aggregate of 10,076,148 tons, and 5,842 sailing craft, aggregating 2,105,688 tons, enter and leave ports on the Atlantic seaboard during a single year. The value of their cargoes is more than a billion and a half of dollars. Our coastwise traffic also is enormous. In one year more than 17,000 sailing vessels and 4,000 steamers enter and leave ports between Maine and Florida. Their cargoes are estimated to be worth \$7,000,000. From these facts one can roughly measure the value of the marine property which the Department of Agriculture, through the work of the Weather Bureau, aims to protect by giving warning of approaching storms.

It is the dream of the meteorologist that some day he will be able accurately to forecast the weather weeks and months in advance. But so far this much-to-be-desired object can be realized only in a dream. What a wonderful conservation of human energy would result were it possible to tell the farmer when the great corn and wheat belts would have abundant rain during the next growing season, or when droughts would parch the vegetation, or truthfully to inform the planter of the South that the approaching season would be favorable or unfavorable to the production of cotton! Effort would be withheld in one part of the country and prodigious energy exerted in another.

When our extensive system of daily observation has been continued for another generation a Kepler or a Newton may discover such fundamental principles underlying weather changes as will

make it possible to foretell the character of coming seasons. If this **discovery** be ever made it will doubtless be accomplished as the **result** of a comprehensive study of meteorological data of long periods covering some great area like the United States. At any **rate** we are certainly now laying the foundation of a great system which will adorn the civilization of future centuries.

At the present time I know of no scientific man who essays to **make** long-range weather predictions, and I would especially caution the public against the imposture of charlatans and astrologists, who simply prey upon the credulity of the people. As storms of more or less intensity pass over large portions of our country every few days during the greater part of the year, and as it is seldom that the weather report does not show one or more storms as operating somewhere within our broad domain, it is easy to forecast thunderstorms about a certain time in July or a cold wave and snow about a certain period in January and stand a fair chance to become accidentally famous as a prophet. You may select any three equidistant dates in January and forecast high wind, snow, and cold for New York city and stand a fair chance of having the fraudulent forecast verified in two out of the three cases; provided that you claim a storm coming the day before or after one of your dates to be the storm which you expected.

I believe it is impossible for any one to-day to make a forecast, based fairly upon any principles of physics or upon any empiric rule in meteorology, for a greater period than one or two days in winter or for more than two or three days in summer; and there are times in winter when the movements of air conditions are so rapid that it is extremely difficult to forecast even for the space of one day. The Weather Bureau takes the public into its confidence in this matter and does not claim to be able to do more than it is possible to accomplish.

Having reached the highest degree of accuracy possible with our present instrumental readings, it becomes necessary to invade new realms if we desire to improve the character of the forecast and to make it of greater utility. I have long realized this, and several years ago determined systematically to attack the problem of upper-air exploration with the hope of being able ultimately to construct a daily synoptic chart from simultaneous readings taken in free air at an altitude of not less than 1 mile above the surface of the earth. During the past ten years there has been much discussion as to the best means of improving weather forecasts by readings secured at high levels. Many stations have been established on mountain peaks; but, unfortunately, the observations from these places have been of little use to us in making the daily forecast.

It is my opinion that plans previously advocated by many for iso-

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lated investigations in the upper air by means of free and uncontrollable balloons, by observers in balloons, or by independent kite stations striving for very great flights, were of little value in getting the information absolutely necessary to the more accurate determination of the mechanics of storms. It is my belief that the only feasible plan is that of simultaneous observations at such uniformly high level as can be attained with kites at many stations. With only a moderate surface wind our improved kites will now ascend easily to the height of one mile or over, and will carry up an automatic instrument, mainly of aluminum, weighing about two pounds, which records temperature, pressure, humidity, and wind velocity.

The Weather Bureau intends to establish tentatively fifteen or twenty stations between the Alleghanies and the Rocky Mountains during the present spring, and to make special effort to secure observations at the same hour at a high level from all the stations, so that the meteorological conditions at that altitude may be compared with those prevailing at the surface of the earth. If we are successful in attaining the desired altitude at enough of our stations each day to give the data from which a synoptic chart can be constructed, we shall then be able to map out not only the vertical gradients of temperature, humidity, pressure, and wind velocity, but also the horizontal distribution of these forces at two levels—one at the earth's surface and the other at the height of one mile. It may be that after this work is done only negative knowledge will be acquired; but, even then, the work will not have been in vain. It will be an instructive study to note the development and progression of storms and cold waves at this high level. At that altitude the diurnal variations cease; there is but little change between the heat of midday and that of midnight; so that storm conditions may be measured without the confusing effects due to immediate terrestrial radiation.

The temperature readings already secured by our use of kites show that in the summer season we live in an extremely thin stratum of warm air; that on the hottest day an ascent of only 500 to 1,000 feet in free air would place a person in a comfortably cool atmosphere; that the temperature at an altitude of 3,000 feet is slightly higher at midnight than at midday; and that changes of wind and of temperature begin at high levels sooner than on the surface of the earth.

It is a problem for the engineer of the twentieth century how to utilize this information so as to give relief during the protracted hot spells of summer to the dense population of great cities, and so that one need not travel to the seashore in order to reach a temperature that is conducive to health and comfort.